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OPERATIONAL EVALUATION OF THE ELECTRO-OPTIC TACTICAL DECISION AID, VERSION 3.1

by

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March, 1997

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The Electro-Optical Tactical Decision Aid (EOTDA) is a tool weather forecasters use to predict target detection ranges and the performance of various electro-optic precision-guided weapon systems. The user inputs environmental and tactical information, such as the expected atmospheric conditions and target and background descriptions. The primary EOTDA output are target detection ranges and thermal contrast information. The EOTDA supports three types of weapon systems: infrared (8-12 μm), visible (0.4-0.9 μm), and laser (1.06 μm). This study is an evaluation of the EOTDA performance of an infrared (IR) weapons system used during a training exercise at Naval Air Station (NAS) Fallon, Nevada in January 1996. In addition, a sensitivity study of the EOTDA parameters was completed. The results showed that the EOTDA predicted ranges within 20% of the observed detection ranges when correct environmental information was available. The most critical parameters required for the EOTDA were moisture, aerosol selection, the target area forecast, and composition of the target and background. Recognizing the strengths and weakness of the EOTDA will help operational users improve electro-optic forecasts and help guide future research and development efforts.

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OPERATIONAL EVALUATION OF THE ELECTRO-OPTIC TACTICAL DECISION AID, VERSION 3.1

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ABSTRACT

The Electro-Optical Tactical Decision Aid (EOTDA) is a tool weather forecasters use to predict target detection ranges and performance of various electro-optic precision-guided weapon systems. The user inputs environmental and tactical information, such as the expected atmospheric conditions and target and background descriptions. The primary EOTDA output are target detection ranges and thermal contrast information. The EOTDA supports three types of weapon systems: infrared (8-12 μm), visible (0.4-0.9 μm), and laser (1.06 μm). This study is an evaluation of the EOTDA performance of an infrared (IR) weapons system used during a training exercise at Naval Air Station (NAS) Fallon, Nevada in January 1996. In addition, a sensitivity study of the EOTDA parameters was completed. The results showed that the EOTDA predicted ranges were within 20% of the observed detection ranges when correct environmental information was available. The most critical parameters required for the EOTDA were moisture, aerosol selection, the target area forecast, and composition of the target and background. Recognizing the strengths and weaknesses of the EOTDA will help operational users improve electro-optic forecasts and help guide future research and development efforts.

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

μm	micrometers
°F	degrees Fahrenheit
K	Kelvin
9999	unrestricted visibility in TAF code
BL	Boundary Layer
BLH	Boundary Layer Height
DOD	Department of Defense
EOTDA	Electro-optic Tactical Decision Aid
FLIR	Forward-looking Infrared
IR	Infrared
IR TDA	Infrared Tactical Decision Aid
MDT	Minimum Detectable Temperature
MRT	Minimum Resolvable Temperature
NAM	Navy Aerosol Model
NAS	Naval Air Station
NFOV	Narrow Field of View
TAF	Terminal Aerodome Forecast
TCM2	Target Contrast Model
TOT	Time over target
WFOV	Wide Field of View
WIDA	Weather Impact Decision Aids
WSO	Weapon Systems Officer
BKN	broken cloud coverage (5/8 to 7/8)
deg	degrees
delta-T	difference in temperature
ft	feet
hft	hundreds of feet
Jan	January
K	Kelvin
kft	thousands of feet
kt(s)	knots
L	local time
M	measured cloud base
mdt	moderate
nm	nautical miles
OVC	overcast cloud coverage (8/8)
SA	standard hourly weather observation
SCT	scattered cloud coverage (0/8 to 4/8)
VRB02	variable winds at two knots
Z	zulu or universal time

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I. INTRODUCTION

A. CONCEPT AND PURPOSE

The Electro-Optical Tactical Decision Aid (EOTDA) was developed by the Air Force in the 1980's in order to assess the performance of air-to-ground weapons systems in the forward-looking infrared (FLIR) (8 - 12 μm), TV (0.4 - 0.9 μm), and laser (1.06 μm) wavelength bands as a function of environmental and tactical conditions. Development of the EOTDA was a major step forward in electro-optic forecasting, improving graphical techniques and calculator computations in earlier use. The current version, 3.1, has been in use throughout the Department of Defense since 1994.

Electro-optic forecasting primarily provides pilots or weapon systems officers (WSOs) predicted target detection and lock-on ranges. Other information is also available, such as target and background thermal contrast; target and background hot-to-cold list; transmissivity; infrared (IR) visibility; absolute humidity; predicted sky, target and background temperatures; and, solar and lunar positions. Appendix A is an example of EOTDA output.

The pilot's concept of operations is to find the target using radar, and then switch over to the FLIR sensor video to spot the target provide terminal guidance. The EOTDA predicts when it is possible to switch from radar to FLIR sensor guidance and tracking. The radar has a longer range but lower resolution. It also places limits on aircraft maneuverability. The FLIR on the other hand, has better resolution but a shorter range and is more dependent on the environment. The pilot must balance the need for accurate target tracking with the possibility of needing to pass over the target area again. The operational community has generally requested a range prediction accuracy of 20% or plus/minus 1 to 2 nautical miles.

The purpose of this thesis is to evaluate the EOTDA's infrared model, the IR TDA, using data from an operational training exercise and by evaluating the sensitivity of the model to user entries. Evaluation of the EOTDA strengths and weaknesses will enhance the program effectiveness for the user, and will direct further research and development. Findings, conclusions, and recommendations will be provided for each case study and for the parameter evaluation. Section III presents the overall conclusions and recommendations.

B. SUMMARY OF FINDINGS

Previous evaluations have focused on the target models, the background models, boundary layer height, and the effects of target heading and view direction on detection range. McGrath (1996) found that the EOTDA (3.1) frigate target model needs improving. Inaccuracies were found in the water, concrete, and asphalt background models (Schemine and Dunham 1994). Keegan's (1990) evaluation of the boundary layer model showed detection ranges to be overpredicted when the sensor is above the specified boundary layer height (BLH). He also found the detection range to be sensitive to target heading and view direction.

In interviewing pilots, the majority are interested in the bottom line, ballpark detection range for their specific mission and if the target will be colder or hotter than the background. As a planning tool, however, the EOTDA is also effective in providing the best time of day for a mission, best sensor height and view direction, and times of thermal crossover. Both the flying and weather communities agree on the importance of accurate input data and communication with each other.

The results of this analysis describe the performance and prediction accuracy of the EOTDA. Overall, the EOTDA provides accurate predictions when the input data is accurate. Thus, it is important for the EOTDA user to know as much detail about the target and background in addition to entering expected weather conditions as accurately as possible. All predicted detection range percentage errors in the exercise evaluation were below 15%. Having detailed, written target descriptions and photographs of the target area, watching video footage, and talking with the pilots and intelligence community at Fallon Naval Air Station, resulted in the accurate EOTDA output.

In the sensitivity study, three parameters were found to be significant--the dewpoint temperature, wind speed, and visibility. Dewpoint temperature describes the number of water molecules in the air. High wind speeds moderate the thermal contrast of target and background. Visibility reflects the amount of particulates in the atmosphere due to the air mass type, precipitation, or other obscurations. On the other hand, the EOTDA was not sensitive to albedo (the general target area albedo), scene complexity, or certain backgrounds. Details are provided in the evaluation and sensitivity study.

There were some deficiencies found in the EOTDA. One detection range category, the minimum detectable temperature (MDT) detection range, did not have solutions in most of the EOTDA runs. In the other category of minimum resolvable temperature (MRT), the Wide Field of View (WFOV) detection ranges were either not resolved or were underestimated in most runs. Some of the target models need improvement, such as the frigate, scud launcher, and bridge. Some types of weather had overpredicted detection ranges. These include freezing precipitation, freezing drizzle, and moderate intensity rain showers. All of the findings mentioned from earlier studies were confirmed in this evaluation.

C. OVERVIEW OF THE IR TDA

Three component models make up the IR TDA: the target model, the transmittance model, and the sensor performance model. The target model calculates the strength of the electro-optic signal arriving at the sensor at zero range. The transmittance model evaluates signal attenuation between the target and sensor. The sensor model evaluates the instrument and human factors determining probable detection of the target by the operator. (Gouveia *et al.* 1994)

1. Target Model

In the target model, the program calculates the difference in radiance between target and background over the wavelength band from 8 to 12 μm. This radiance difference is then converted to a temperature difference. The thermal model converts the physical temperature of target and background to an equivalent blackbody temperature.

The thermal model is based on the Target Contrast Model #2 (TCM2), which treats the target as a three-dimensional network of nodes that exchange heat with one another and with the environment, providing a detailed thermal signature. The number of nodes per target varies from 17 nodes (fuel tank) to 68 nodes (Apache AH-64 helicopter). The principal phenomena interacting to produce the thermal scene are radiative heating and cooling; mass and heat transfer effects of evaporation, condensation, sublimation, and precipitation; the thermal properties of the target and background (e.g., emissivity, heat capacity, heat conductance, and coefficients of convective heat exchange); and thermal transfer of wind. (Gouveia *et al.* 1994)

The EOTDA includes 18 standard targets to select from, as well as eight classes of generic targets which the user specifies. Eight types of backgrounds are available: vegetation, soil, snow, water, concrete, asphalt, swamp, and rocky field. Each background is further described by moisture, coverage, depth (for water background), and density of the surface type. For example, a vegetation background can be defined as dry and sparse or moist and dense. The EOTDA is usually used with multiple background instances for each run. The program serves to use the first entered background as the primary background, which is used to compute reflected ground radiation. Each entered background is not considered independently. It is important, therefore, to enter the most representative background first.

2. Transmittance Model

The transmittance model evaluates the attenuation of the signal by atmospheric constituents between target and sensor. The attenuation model consists of four components: molecular, aerosol, precipitation, and battlefield-induced contaminants. Molecular attenuation is due primarily to water vapor and is related to temperature and moisture. The EOTDA model contains 17 different types of aerosols from two basic models--LOWTRAN 7 (Kneizys *et al.* 1988) and the Navy Aerosol Model (NAM) (Gouveia e*t al.* 1994). The rural, urban, maritime, and tropospheric aerosols are dependent on ordinary visibility and relative humidity along the sensor-to-target path. Desert aerosol extinction is dependent on wind speed. Attenuation due to snow, fog and the camouflage smokes is related to visibility. Rain attenuation is modeled on the basis of rain rate. (Gouveia *et al.* 1994) NAM, which is divided into nine categories, characterizes particles that result from ocean spray. Its extinction coefficient depends on relative humidity, an air mass parameter, the instantaneous wind speed, and an average wind speed over the past 24 hours.

3. Sensor Performance Model

The sensor performance model determines the range when the actual signal received by the sensor equals the threshold signal for detection or lock-on. Normally, the signal decreases as the target-to-sensor range increases. The threshold signal is determined by the target's apparent size (angular subtense) as viewed from the sensor. The smaller the subtense, the larger the threshold value of the signal. Thus, detection range usually increases with increasing target size for fixed values of delta-T (the temperature difference between target and background) and transmittance.

The TCM2 computes a mean target temperature and it also identifies the hottest and coldest of the visible nodes. It then identifies which of these has the greater contrast with the background. This identified node temperature is called the "minimum detectable temperature" (MDT). An MDT range is calculated from this node temperature and its projected area in the sensor performance model. Another temperature, the "minimum resolvable temperature" (MRT) is calculated from the mean target temperature. Its corresponding range is calculated from the MRT. The MRT range does not increase beyond a certain maximum value of target size. These limiting values reflect the optical resolution limit of the particular sensor. Thus, there is a maximum value the MRT detection range cannot exceed, regardless of the delta-T value. Because of sensor characteristics and differences in the background temperature, the hot-cold spot temperature, and the mean target temperature, the EOTDA User's Manual advises making no prediction of detection range based on delta-T alone. (Gouveia *et al.* 1994)

II. METHODOLOGY

A. GENERAL

The evaluation of the EOTDA in this project consists of two components. The first evaluates prediction of FLIR range by the EOTDA during a training exercise in January 1996 at the Strike Warfare Weapons School at Fallon Naval Air Station, Nevada. The original predicted detection ranges from the EOTDA are compared with the observed detection ranges reported by the pilots. Collected observational weather data and detailed target and background were then utilized in running new EOTDA predictions and comparing with the original data. The second evaluation analyzes the dependence of EOTDA range prediction on the input parameters for specific case studies during the validation. The sensitivity analysis confirms strengths and deficiencies of the EOTDA.

B. NAVY FALLON EXERCISE EVALUATION

1. Overview

Data compiled from this month-long exercise consists of prediction ranges from the original EOTDA runs; the recorded weather observations from NAS Fallon; the pilot-observed target detection ranges; detailed target and background information; topographical maps of the Nevada area; photographs; video footage; and bomb range target diagrams. Two important pieces of information not available are the weather data entered into these original EOTDA runs and the specific target data. Without this information, it is difficult to determine exactly what factors caused the original forecasts to be less accurate. However, the new EOTDA predictions provide greater knowledge and familiarity of the EOTDA.

One assumption in this evaluation is that the weather recorded at Navy Fallon is the same weather that occurred at the bomb range. Navy Fallon is the nearest location with a weather observer recording the weather conditions (approximately 30 miles northwest of the bomb range). Navy Fallon's surface elevation is 3,934 feet, and the bomb range elevation is 4,250 feet. Because Sand Spring Mountain Range runs north-south between Fallon and the bomb range, weather will vary between these locations for a given time. But because the entire state of Nevada has an arid climate, this assumption is justified. (See map in Appendix B). The new EOTDA runs use actual observations rather than forecast weather parameters. This is one probable reason why the new EOTDA detection ranges are more accurate than the original.

Detection ranges given in this thesis are MRT ranges in the narrow field of view (NFOV), unless otherwise stated, mainly because the wide field of view (WFOV) output is questionable. Some WFOV values were either not computed or were constrained to an unreasonably low upper limit value. Finally, the actual view directions during each mission are not known. Therefore, detection ranges were averaged over all view directions. Experience has shown this to be a reasonable and reliable approach.

2. Evaluation

Table 1 below summarizes the observed and original EOTDA predicted detection ranges from the January 1996 exercise. Each flying day had good weather. On 19 January, the runway was wet from snow and rain the previous day, and the winds were gusting up to 22 knots. The observed detection ranges were the lowest on this day, and forecast errors of 30 and 70 percent were the highest on this day. Table 1 summarizes the original ranges. Table 2 compares the observed detection ranges with the EOTDAs run in this evaluation. Each forecast was improved except for the 9 Jan/1900L forecast, but the error on that run was only -4.2%.

Date	**Time (L)**	**Target**	**Sensor Height (ft)**	**Observed Range (nm)**	**Predicted Range (nm)**	**Error (%)**
8 Jan	1800	Bunker	18,000	11.0	8.9	-19.1
9 Jan	1800	Bunker	22,000	15.0	12.6	-16.0
9 Jan	1900	Bunker	12,000	12.0	12.3	2.5
10 Jan	1330	Runway	26,000	20.0	25.3	26.5
10 Jan	1800	Runway	26,000	20.0	16.0	-20.0
19 Jan	1700	Bunker	23,000	6.0	7.8	30.0
19 Jan	1700	Runway	23,000	12.0	20.4	70.0

Table 1. Summary of January 1996 pilot-observed detection ranges in nautical miles (nm) versus the original EOTDA predicted ranges with percentage error.

Date	Time (L)	Target	Sensor Height (ft)	Observed Range (nm)	Predicted Range (nm)	Error (%)
8 Jan	1800	Bunker	18,000	11.0	10.9	- 0.9
9 Jan	1800	Bunker	22,000	15.0	13.2	-12.0
9 Jan	1900	Bunker	12,000	12.0	11.5	- 4.2
10 Jan	1330	Runway	26,000	20.0	17.5	-12.5
10 Jan	1800	Runway	26,000	20.0	19.3	- 3.5
19 Jan	1700	Bunker	23,000	6.0	6.2	3.3
19 Jan	1700	Runway	23,000	12.0	11.7	- 2.5

Table 2. Summary of January 1996 pilot-observed detection ranges versus the new evaluation EOTDA predicted ranges with percentage error.

In the new EOTDA predictions, the bunker and runway were constructed as accurately as possible given the constraints within the generic target models. The bunkers in the bombing range at NAS Fallon are not actual bunkers. These makeshift bunkers are composed of steel engine containers, made into a berm with mixed earth on the sides. Table 4 describes the bunker construction in the EOTDA.

The bombing range runway is a dirt runway. Instead of using the generic runway model, which only has two composition materials--concrete and asphalt--the runway was built using the "off menu" target model with soil as the composing material. The off menu target is an option in the generic target model, which allows the user to construct a target that is not representative in the standard or generic target models. Results were more accurate using this runway built as an off menu target rather than constructing a concrete or asphalt generic runway. Tables 3 describes the construction of the runway target. Photographs of each target are included in Appendix C. As each mission is evaluated, the findings will be stated. A summary of conclusions and recommendations is provided in Section III.

Runway Composition	
Length	3280.5 ft
Width	200 ft
Height	0.03 ft
Background	Soil
Soil Type	Loam
For Dry Runway	Dry surface moisture, Dry depth moisture
For Wet Runway	Wet surface moisture, Intermediate depth moisture
For Intermediate Runway	Dry surface moisture, Intermediate depth moisture

Table 3. NAS Fallon runway target composition.

Bunker Composition	
Height	14 ft
Width	35 ft
Length	40 ft
Door Radius	13 ft
Door Thickness	0.07 ft
Door Surface	Rusted steel
Door Material	Steel
Sides Surface	Bare concrete - uncolored
Sides Material	Concrete - normal
Earth Surface Layer Material	Normal sand
Earth Surface (Dry)	Normal soil surface
Earth Surface (Wet)	Wet soil surface
Earth Subsurface Material	Normal sand/sandy soil

Table 4. NAS Fallon bunker target composition.

a. 8 Jan/1800L, Bunker, Sensor Height 18,000 feet

Weather conditions were very good on this day--scattered middle cloud, thin overcast cirrus, unrestricted visibility, and calm to light and variable winds. During this test, no MDT values of any kind (detection range, delta-T values, target or background temperatures) were computed for the bunker. The output stated either "no value computed" or "no solution possible." Also, the WFOV MRT detection range was the same for all view directions--20.2 kft (3.3 nm); but, the NFOV MRT delta-T values for each view direction varied. Apparently, the sensor's optical resolution limit was reached. The average dewpoint temperature from 9 Jan 96/0900Z to the time over target (TOT) of 10 Jan 96/0200Z was 31 °F. Experience has shown best results are obtained using the average dewpoint temperature from the start of the terminal aerodome forecast (TAF) to the TOT. The IR TDA uses six hours of data prior to TOT to initialize (Gouveia *et al.* 1994). Predictions were made with several selected aerosols and backgrounds. Case 3 in Table 5 shows the best agreement with the observed ranges. Because the view direction was not known, the predicted detection range was determined by averaging the NFOV MRT detection ranges over all view directions.

Possible reasons why the original EOTDA forecast was too low would be that either a higher dewpoint, higher wind speed, broken versus thin cirrus deck, or desert aerosol was input (or a combination of these). In fact, when all of these conditions were entered in to the EOTDA (35°F dewpoint temperature and winds at five knots), 8.9 nm was the averaged NFOV MRT detection range, as originally forecast.

	Aerosol	Background(s)	Detection Range (nm)
1	Rural	Dry Soil	11.9
2	Rural	Dry Rocky Field	9.8
3	Rural	Dry Soil & Rocky Field	10.9
4	Desert	Dry Soil	11.2
5	Desert	Dry Rocky Field	9.0
6	Desert	Dry Soil & Rocky Field	10.1

Table 5. 8 Jan 96/1800L evaluation of bunker target.

b. 9 Jan/1800L, Bunker, Sensor Height 22,000 feet

The general weather on this day consisted of surface winds less than ten knots, middle and high level cloud ceilings, unrestricted visibility and the average relative humidity fifty percent. The recorded weather observation at TOT of 9 Jan/1800L was:

SA 0156 60SCT E120BKN 200OVC 10 45/35 0207

This observation says that the hourly observation at 10 Jan 96 at 0156Z, the clouds were scattered at 6,000 feet; the ceiling with broken coverage was estimated at 12,000 feet; clouds (cirrus) were overcast at 20,000 feet; the visibility was ten miles; the air temperature was 45 °F; the dewpoint temperature was 35 °F; and , the surface winds were from the northeast (20 degrees) at a speed of seven knots. Because the EOTDA gives no solutions when the sensor is above an overcast deck, a broken layer at 20,000 feet was entered into the EOTDA.

The average dewpoint temperature from 09/0800Z to 10/0200Z was 28 °F; this was the input dewpoint. Surface winds were left as recorded--seven knots out of the northeast. With a rural aerosol, the average detection range was 11.0 nm, ranging from 8.8 to 13.1 nm.

In the next run, the aerosol was changed to tropospheric since most of the slant path is above the boundary layer. Here, the average detection range increased to 12.6 nm, an increase of 14.5%. The error from the observed range of 15.0 nm is -16.0%. In another run, when the cirrus deck is further reduced to scattered, the average detection range is 12.65 nm; no significant difference. The best results with realistic input was with a tropospheric aerosol and broken middle and high level cloud decks. If the highest detection range of 13.2 nm was used rather than the average range, the error is -12.0%.

There are some interesting items in this case, which were not evident in the previous evaluation. No solutions resulted for the WFOV MRT detection ranges and delta-T values. The only significant difference with this evaluation is the sensor height increasing 4,000 feet. Also, the NFOV MRT detection range has a maximum value of 13.2 nm for this target size and sensor. Table 6 summarizes the results.

	Aerosol	**Detection Range (nm) Highest / Average**
1	Rural	13.1 / 11.0
2	Tropospheric	13.2 / 12.6

Table 6. 9 Jan 96/1800L evaluation.

c. 9 Jan/1900L, Bunker, Sensor Height 12,000 feet

Light rain showers occurred one hour after the 1900L TOT. The recorded observation at this time of 10/0300Z consisted of broken clouds measured at 11,000 feet;

overcast clouds at 20,000 feet; ten miles visibility; air temperature 46 °F; dewpoint temperature 35 °F; and, calm winds. This weather observation is encoded as follows:

SA 0256 M110BKN 200OVC 10 46/35 0000

Since the observed detection range was 12.0 nm, it is assumed that no rain showers occurred at the bombing range until after TOT. Again, no MDT values were computed, and again, the WFOV MRT detection ranges were the same for all view directions. Since the corresponding WFOV MRT delta-T varied with view direction, it can be concluded that the maximum WFOV MRT detection range value was reached due to the sensor's optical resolution limit. When only the aerosol was changed, the delta-T values did not change. As in the previous cases, best agreement occurred when using the average dewpoint temperature of 30 °F rather than the 35 °F TOT dewpoint temperature.

The parameters examined in this series were the aerosol, dewpoint temperature, wind speed, and cloud cover. The dewpoint temperature was the most significant parameter in this set having a percentage difference in average detection range of 7.5%. The detection range increases one nautical mile when the dewpoint temperature was lowered by 5 °F. This is expected since the rural aerosol is dependent on relative humidity and visibility. Table 7 summarizes the results. Case 3 had the most representative conditions in accordance with the reported weather observation.

	Aerosol	Clouds (coverage hft)	Dewpoint (°F)	Wind (DegKt)	Detection Range (nm)
1	Rural	BKN110 OVC200	35	02007	10.4
2	Rural	BKN110 BKN200	30	02007	11.2
3	Rural	BKN110 OVC200	30	CALM	11.4
4	Rural	BKN110	30	CALM	11.7
5	Desert	BKN110 BKN200	30	CALM	11.3

Table 7. 9 Jan 96/1900L evaluation.

d. 10 Jan/1330L, Runway, Sensor Height 26,000 feet

This mission occurred during daylight hours, and it had the highest sensor height. Weather conditions were calm winds, dry air, scattered clouds, 20 miles visibility, a49 °F air temperature, and 35 °F dewpoint temperature. The average dewpoint temperature was 34 °F. The observed detection range was 12.0 nm.

Two backgrounds were entered to create an accurate background scene against the runway target. The first entered background was a rocky field with low quartz content, dry surface moisture, and dry depth moisture. The second background was loam soil, the same soil as the runway. Each background is a separate entry, and the EOTDA calculates detection ranges and temperatures separately for each. Because of the dry atmosphere and sensor height of 26,000 feet, the tropospheric aerosol was used. Since the reported visibility was 20 miles, 40,000 meters was entered in the EOTDA TAF rather than the customary unrestricted visibility code "9999", which represents seven miles visibility. Changing the visibility from "9999" to "40000" increased the detection range one mile for the tropospheric aerosol and nearly five miles with the rural aerosol. Also, the lowest detection ranges occurred when the view directions were the same as the target headings, due to the length of the runway. Table 8 summarizes the results. The detection range of 19.5 nm in case 7 was closest to the 20.0 nm observed detection range.

	Aerosol	Visibility (nm)	Primary Background	Detection Range (nm)
1	Tropospheric	7	Dry Soil	9.1
2	Tropospheric	20	Dry Soil	10.2
3	Tropospheric	7	Dry Rocky Field	24.3
4	Tropospheric	20	Dry Rocky Field	25.7
5	Rural	7	Dry Soil	6.1
6	Rural	20	Dry Soil	9.2
7	Rural	7	Dry Rocky Field	19.5
8	Rural	20	Dry Rocky Field	24.3

Table 8. 10 Jan 96/1330L evaluation.

Again, there were no MDT solutions even though a cold spot was specified with this "off menu" target. With off menu targets, the EOTDA user is prompted to enter the mean and/or the hot/cold spot temperatures. Both a mean temperature and a cold spot temperature (the runway was observed to be colder than the background) was entered.

It was found in this case that delta-T values do not vary with view direction for targets wh ich have no height, such as a runway. Another finding in this case was that the WFOV MRT detection ranges did change correspondingly as the NFOV MRT ranges changed per view direction. It can be concluded that the optical resolution limit for this particular target was not reached.

e. 10 Jan/1800L, Runway, Sensor Height 26,000 feet

The weather continued to improve on the tenth of January. The recorded weather observation was:

SA 0156 200 -SCT 10 38/33 0306

Because of the 26,000-foot sensor height, the tropospheric aerosol was again examined versus the rural and desert aerosols. It gave results closer to the observed range than the rural and desert aerosols. The reported visibility of 10 nautical miles was entered in the EOTDA TAF. The detection ranges from both the rocky field and soil backgrounds were combined and averaged, giving a forecast detection range of 19.3 nm, an error of -3.5%. The EOTDA runway temperature was colder than the backgrounds, in agreement with pilot reports. In this case there were also no MDT solutions. The recorded weather data gave accurate output, including a correctly predicted colder runway.

f. 19 Jan/1700L, Bunker, Sensor Height 23,000 feet

Results from this mission show the significance of wind speed. A five knot increase in speed decreased the average NFOV MRT detection range from 9.0 to 7.0 nm. The general weather on this day was variable cloudiness, unrestricted visibility, a drying air mass as the day progressed, a wet runway from the snow and rain the previous day, and northwesterly winds with occasional gusts up to 22 knots. The average dewpoint was 28 °F up until TOT. The recorded weather observation at 19/1700L (20/0100Z) was:

SA 0056 65SCT 75SCT 110SCT 10 41/22 3109G16

It was assumed that the ground was still wet from the precipitation the day before, since a wet runway was reported at NAS Fallon throughout the day until 1400L/2200Z hours. The question to consider was how should the wetness be specified. The total measured water equivalent precipitation at NAS Fallon on 18 January was 0.15 inches. The best results using the most realistic data was an averaged NFOV MRT detection range of 6.2 nm. (The observed detection range was 6.0 nm.) Seven different runs gave acceptable average detection ranges between 6.0 and 7.0 nm. The eighth run showed the significance of wind speed on detection range; there was an increase of 2.0 nm with a decrease of five knots. Table 9 shows the results as the parameters were modified. Note that cases 3, 5, and 6 have the same average detection range. Because relatively high winds occurred, the desert aerosol was applied in this case. With the desert aerosol, wet soil versus normal soil did not significantly change the detection ranges (see cases 4 and 6). When the rural and tropospheric aerosols were used, the detection ranges exceeded 13 and 16 nm, respectively; over twice the observed detection range. These results are not shown in Table 9.

	Clouds (hft)	Dewpoint (°F)	Wind (DegKt)	Bunker Moisture	Background Moisture	Detection Range (nm)
1	BKN110	30	30020	Wet Soil Surface	Wet Surface Intermediate Depth	6.5
2	BKN110	30	30020	Wet Soil Surface	Intermediate Surface Dry Depth	6.0
3	SCT110	30	30020	Wet Soil Surface	Intermediate Surface Dry Depth	6.2
4	SCT110	28	30020	Normal Soil Surface	Wet Surface Intermediate Depth	6.8
5	SCT110	28	30020	Normal Soil Surface	Intermediate Soil Surface Dry Depth	6.2
6	SCT110	28	30020	Wet Soil Surface	Intermediate Soil Surface Dry Depth	6.2
7	SCT110	28	30020	Wet Soil Surface	Wet Surface Intermediate Depth	7.0
8	SCT110	28	30015	Wet Soil Surface	Wet Surface Intermediate Depth	9.0

Table 9. EOTDA results for bunker target on 19 Jan 96/1700L hours. Although not shown in this table, the detection ranges using a rural and tropospheric aerosol were 13 nm and 16 nm, respectively. Cloud cover was either broken at 11,000 feet (BKN110) or scattered at 11,000 feet (SCT110).

Out of the 12 test runs performed in this case, none had WFOV MRT detection range solutions. Six of the 12 runs had WFOV and NFOV MDT detection ranges. All previous bunker cases had no MDT solutions. When wet background soil was entered versus dry or intermediately wet soil, MDT values were calculated for both a wet bunker and a dry bunker. No values were computed when the soil was dry or "intermediate" (between wet and dry). It is not known why there are often no MDT solutions. The sample EOTDA in Appendix A shows where MDT ranges are computed and not computed. It also shows where WFOV MRT ranges were resolved and not resolved.

Changing the relative humidity and visibility did not significantly affect detection ranges with the desert aerosol, but a small change in wind speed did; see cases 7 and 8 in Table 9. Choosing the desert aerosol was the only way to get accurate results. As stated in the EOTDA User's Manual, an increase in the delta-T value does not necessarily mean an increase in detection range. For cases 7 and 8 in Table 9, the MRT and MDT delta-Ts varied by only 0.3 degrees Kelvin.

g. 19 Jan/1700L, Runway, Sensor Height 23,000 feet

All conditions are the same as the previous case except for the target. This case demonstrates how significant target dimension is. The bunker covered an area of 1,400 square feet versus the runway's 656,100 square feet. The moisture of the runway and soil background, dewpoint temperature, and aerosol were modified to see the difference in detection ranges. Table 10 summarizes the results. Case 8 was in closest agreement with the observed range of 12.0 nm. Note that with a desert aerosol in case 9, the detection range was 55% of the detection range with a rural aerosol in case 8. Choosing the rural aerosol detection range in this mission is not consistent with the previous bunker target mission. This shows both the uncertainty of what the pilot will observe and the significance of aerosol selection in the EOTDA.

	Aerosol	Dewpoint (°F)	Wind (DegKt)	Runway Moisture	Background Moisture	Detection Range (nm)
1	Rural	28	30015	Wet Surface Intermediate Depth	Wet Soil Sfc Intermediate Depth	13.0
2	Desert	28	30015	Wet Surface Intermediate Depth	Wet Soil Sfc Intermediate Depth	6.5
3	Rural	30	30015	Wet Surface Intermediate Depth	Wet Soil Sfc Intermediate Depth	15.5
4	Desert	30	30015	Wet Surface Intermediate Depth	Wet Soil Sfc Intermediate Depth	8.2
5	Tropospheric	30	30015	Wet Surface Intermediate Depth	Wet Soil Sfc Intermediate Depth	18.3
6	Rural	28	30020	Wet Surface Intermediate Depth	Wet Soil Sfc Intermediate Depth	13.1
7	Rural	28	30020	Intermediate Surface Dry Depth	Wet Soil Sfc Intermediate Depth	12.3
8	Rural	28	30020	Dry Surface Dry Depth	Intermediate Soil Surface Dry Depth	11.7
9	Desert	28	30020	Dry Surface Dry Depth	Intermediate Soil Surface Dry Depth	6.5
10	Rural	28	30020	Dry Surface Intermediate Depth	Wet Soil Sfc Intermediate Depth	16.5

Table 10. EOTDA results for the runway target 19 Jan 96/1700L hours.

In summarizing the results of this mission, five of the 13 total runs had prediction ranges within the 20% error standard. There were no MDT solutions even though a cold spot (two degrees colder than the mean target temperature and covering a 5% projected area) was identified with this off menu target. No explanation can be given, except that the MRT delta-T value was greater than the MDT delta-T values as in the previous case. All the runs had WFOV MRT solutions. Changing the dewpoint by two degrees, increasing the wind speed by five knots, and only slightly modifying the moisture made little difference in the detection ranges. The selection of aerosol was the key parameter in this case (see cases 1, 2, and 5 in Table 10). Another significant factor was when the soil surfaces of the runway and soil background were contrasted dry and wet (see cases 8 and 9) when the rural aerosol was used.

3. Conclusions

Based on this exercise evaluation, it is concluded that the EOTDA is an effective forecasting tool when the input atmospheric conditions and target and background descriptions are accurate. The low percentage errors in Table 2 can be attributed to this.

The most important meteorological parameters in this study were the aerosol type, wetness or dryness of the target and backgrounds, the dewpoint temperature when the rural aerosol is used, wind speed with a desert aerosol, the forecasted timing of precipitation, the low and middle cloud coverage, and the visibility. Significant operational parameters were the sensor height, the target size, and the characteristics of the background (i.e., wet versus dry soil).

The least important input parameters in this comparison were the scene complexity, the high cloud cover, scattered middle cloud, and the wind direction. Scene complexity is actually an important factor in target detection, but the EOTDA does not consider it is as such. Unless the target has a high temperature contrast with other similar objects in a cluttered background, the pilot needs extra time to find a particular target in a cluttered target area.

Unreliable EOTDA predictions were the MDT values and the WFOV MRT values. For each case, five to twelve prediction runs were done, approximately 40 total. Out of all of these, only six of the twelve runs for the 19 Jan 96/1700L mission (bunker target) had MDT output values. The correlation was that all EOTDA runs with MDT values had higher delta-T values than the corresponding MRT values. A correlation could not be found for the underestimated or unresolved WFOV MRT detection ranges.

Four of the missions to consider closely in Table 2 are the bunker target on 9 Jan/1800L versus 19 Jan/1700L and the runway target on 10 Jan/1800L versus 19 Jan/1700L. Scattered clouds, light winds and 59% relative humidity on 9 and 10 January gave higher observed detection ranges for the bunker and runway (40% and 60%, respectively) when compared to the windy, 35% relative humidity, and wet ground conditions on 19 January. Though the relative humidity on 10 January was considerably higher than on 19 January, the wet ground and windy conditions on 19 January moderated the air, target, and background temperatures; thus, reducing the thermal contrast and detection ranges significantly.

B. EOTDA PARAMETERS SENSITIVITY STUDY

1. Overview

Each meteorological and operational parameter is isolated to evaluate its sensitivity. All parameters were held constant except for the one being evaluated. Two missions from the exercise evaluation were randomly selected--the bunker target on 9 Jan 96 at 1900L and the runway target on 19 Jan 96 at 1900L. In section 2f of this sensitivity study, the visibility and weather evaluation, different baseline conditions were used in order to use reasonable sky and wind conditions for each particular type of weather. For example, clear skies were used with fog, haze, and sand. Low clouds were included with precipitation. Wind speeds of 25 knots were entered when evaluating sand storms and dust storms. The mission dates and times of the bunker (9 Jan 96/1900L) and runway (19 Jan 96/1700L) were kept the same with two exceptions. When testing air temperature and dewpoint temperature, the maximum temperature time of the day (1300L or 2100Z) was entered as the execution time in the EOTDA, the sky was clear and winds were calm in order to see the maximum effect with temperature changes. The sensitivity and findings of each parameter are discussed and illustrated in each parameter section. The general conclusions of the exercise evaluation and this sensitivity study are discussed in Section III.

2. Meteorological Parameters

a. Air Temperature

In the transmittance model, air temperature and dewpoint determine the molecular component of extinction for the attenuation of longwave IR radiation propagating through the atmosphere. In this test, the temperature was modified in five degree (°F) increments from 35 °F to 100 °F with the dewpoint held constant at 35 °F. Other conditions held constant include rural aerosol, calm winds, unrestricted visibility, clear sky, sensor height (20,000 feet), continental albedo, rocky field background, and two standard targets--scud launcher and bunker. Figure 1 illustrates the results. The scud launcher detection range dropped rather dramatically when the air temperature increased from 40 °F to 45 °F, because at 45 °F, it became slightly warmer than the rocky field background. It had previously been colder than the background with a larger delta-T.

Air temperature modification alone did not make a significant difference. The IR visibility increased only about four nautical miles with an increase of 65 °F, a 93% decrease in relative humidity. Since there was no change in the mixing ratio, the detection range was not affected by changes in water vapor amount. Most of the change was probably due to radiative effects. The increase in average detection range for the scud launcher and bunker are three miles (4.6%) and five miles (7.7%), respectively.

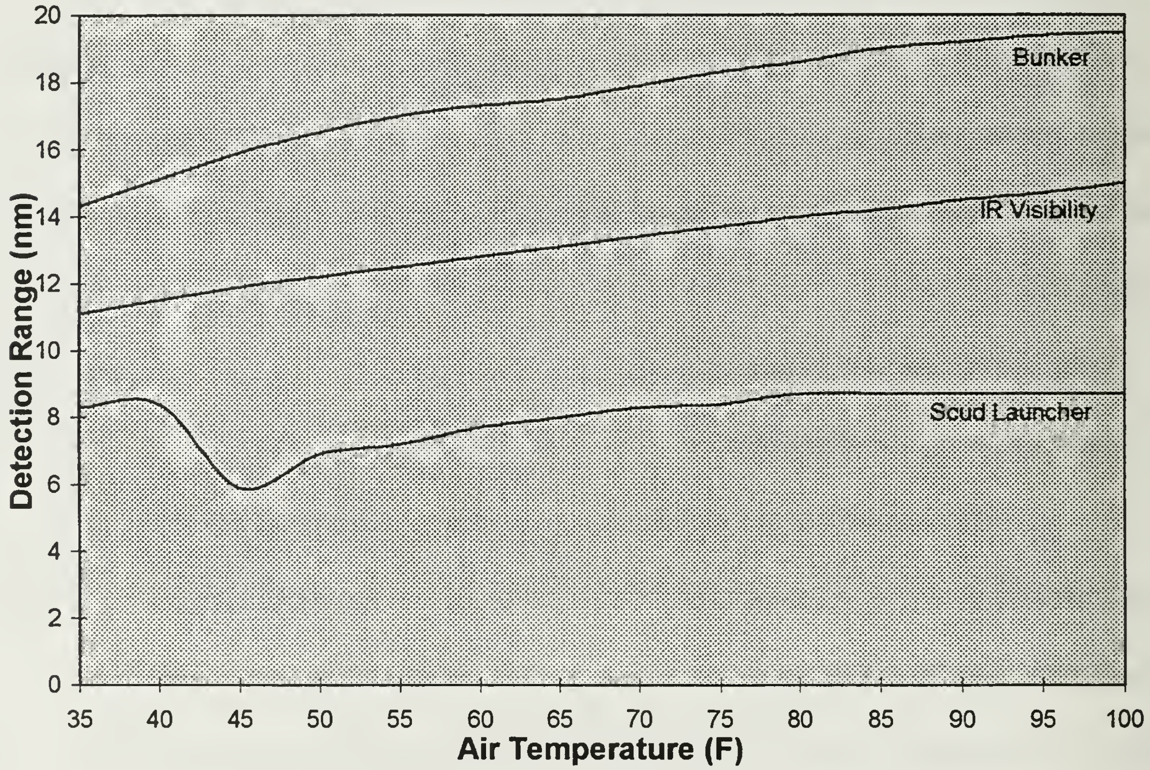


Figure 1. Detection range and IR visibility as a function of temperature.

b. Dewpoint Temperature

Dewpoint temperature plays a key role due to absorption of the thermal signal by water vapor. In one sensitivity study with the scud launcher and standard bunker targets, a 25 °F dewpoint temperature increase decreased the IR visibility by 32.4 % and decreased the average detection ranges by 4% and 25%, respectively. The detection ranges shown in Figures 1 and 2 lead to the conclusion that there is a model deficiency with the scud launcher. In two other tests, the average detection range decreased 20% with an asphalt runway and 8% with a generic bunker. Thus, the type of target affects the sensitivity of detection range to moisture.

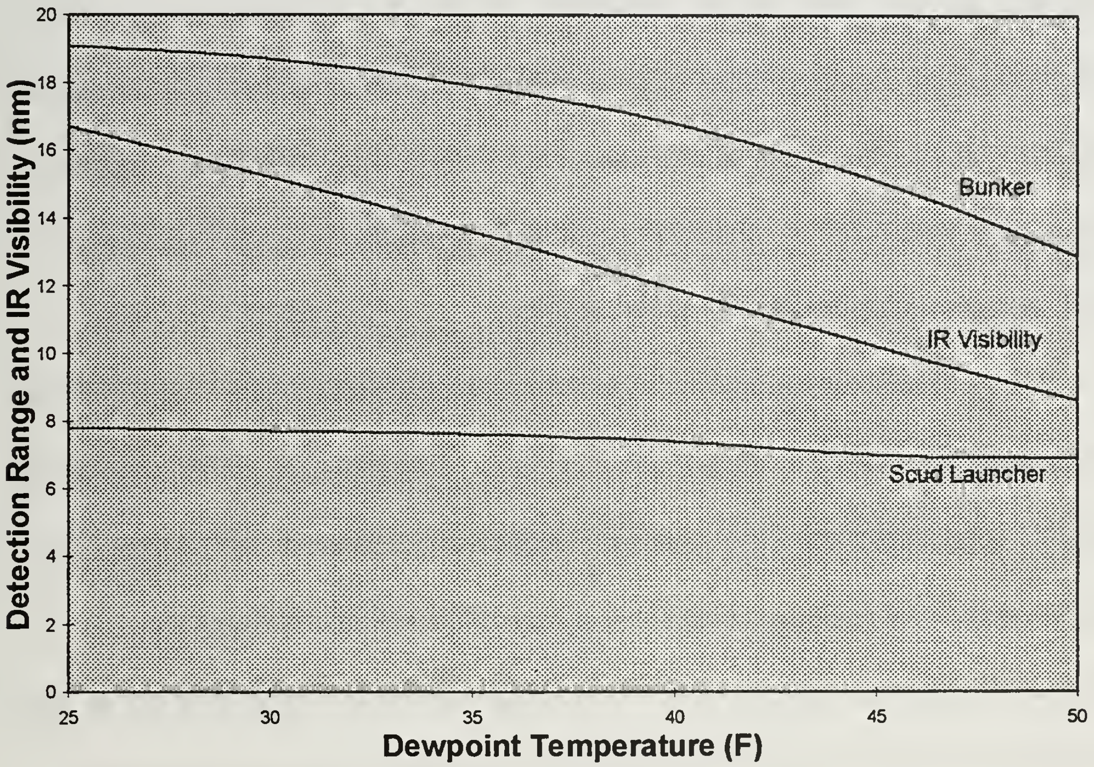


Figure 2. Detection range and IR visibility as a function of dewpoint temperature.

c. Aerosols

The EOTDA has 17 types of aerosols in two groups--one developed from the original LOWTRAN code (Kneizys *et al.* 1988) and the other from the Navy Aerosol Model (Gathman and Davidson 1993). The LOWTRAN aerosols are: desert, maritime, white phosphorous, urban, rural, fog oil, tropospheric, and hexachloroethane. The others are NAM aerosols. The target area air mass characteristics determine the aerosol selection. It is a significant parameter, as seen in Tables 11 and 12. In the transmittance model, one of the four attenuation coefficients is aerosol extinction. Extinction for the rural, urban, maritime, and tropospheric aerosols is dependent on visibility and relative humidity along the path of longwave IR radiation propagating through the atmosphere. Extinction due to the desert aerosol is dependent on wind speed. Extinction due to fog and the camouflage smokes is modeled on visibility. The nine categories of NAM aerosols characterize particles that result from ocean spray. The extinction coefficient depends on relative humidity, an index of continentality for the air mass, instantaneous wind speed, and the average wind speed for the past 24 hours.

The nine categories are divided by antecedent surface winds and target area air mass. Light winds refer to wind speeds from calm to 10 knots. Moderate wind speeds are from 11 to 20 knots, and wind speeds greater than 20 knots are strong. Strong continental conditions apply to a target area within 150 km of an urban area and downwind of an urban pollution source. Open ocean conditions is used when the air mass of a target area has been over the ocean for six or more days. If neither of the above conditions apply, the EOTDA user selects the "Intermediate Conditions" category (Gouveia *et al.* 1994). The aerosols that strongly affect detection ranges are the LOWTRAN aerosols (see lines 1-5, 10-12 in Table 11 and lines 1-5, 12-14 in Table 12), but NAM aerosols seem to have little effect.

Aerosol	Average NFOV MRT Detection Range (nm)
1. Desert	9.6
2. Maritime	13.5
3. White Phosphorous	14.3
4. Urban	14.4
5. Rural	15.1
6. Maritime - Continental, Strong Wind	19.5
7. Maritime - Intermediate, Strong Wind	19.9
8. Maritime - Open, Strong Wind	20.1
9. Maritime - Continental, Mdt Wind	20.7
10. Fog Oil	20.8
11. Tropospheric	20.9
12. Hexachloroethane	21.1
13. Maritime - Intermediate, Mdt Wind	21.2
14. Maritime - Open, Moderate Wind	21.4
15. Maritime - Continental, Light Wind	21.7
16. Maritime - Intermediate, Light Wind	22.1
17. Maritime - Open, Light Wind	22.3

Table 11. Detection range versus aerosol for runway target on 20 Jan 96/0100Z.

Aerosol	Average NFOV MRT Detection Range (nm)
1. Desert	7.5
2. Maritime	8.1
3. White Phosphorous	8.7
4. Urban	8.7
5. Rural	9.1
6. Maritime - Continental, Strong Wind	10.2
7. Maritime - Intermediate, Strong Wind	10.5
8. Maritime - Open, Strong Wind	10.6
9. Maritime - Continental, Moderate Wind	11.0
10. Maritime - Intermediate, Moderate Wind	11.4
11. Maritime - Open, Moderate Wind	11.5
12. Fog Oil	11.5
13. Hexachloroethane	11.6
14. Tropospheric	11.6
15. Maritime - Continental, Light Wind	11.6
16. Maritime - Intermediate, Light Wind	12.0
17. Maritime - Open, Light Wind	12.2

Table 12. Detection range versus aerosol for bunker target on 10 Jan 96/0300Z.

d. Boundary Layer

The EOTDA allows the user to describe the atmosphere as two homogeneous layers with one layer extending from the ground up to the user-specified boundary layer height (BLH) and the upper layer extending from the BLH to the sensor height. The transmittance model then confines weather parameters, such as fog and haze, within the boundary layer. If the atmosphere is specified to be one layer from the ground to the sensor height, the transmittance model assumes all relevant weather parameters are equal to their surface values along the entire path between the target and sensor.

When a two-layer atmosphere is created, the user can choose a default atmosphere. The default defines an upper layer atmosphere that is clear and dry with a tropospheric aerosol. Alternately, the user can specify the average upper layer air temperature, dewpoint temperature, and aerosol.

In testing this with data from the NAS Fallon exercise, the BLH was set at 1,000 feet. Applying the default, the EOTDA calculated a 35 nm detection range, whereas the observed range was 12.0 nm. With a one-layer atmosphere (where the BLH is greater than or equal to the sensor height), the detection ranges were 15.3 nm and 11.0 nm for the rural and desert aerosols, respectively. When the upper layer visibility was lowered and a rural aerosol was selected, the detection ranges aligned closer to the observed range (see Figure 6). The user enters one average air temperature and dewpoint temperature for the upper layer.

Figures 3 through 6 illustrate the effects on detection range with different boundary layer heights and sensor heights. Figures 3 and 4 reflect the effects of rain showers that occurred on 10 Jan 96 from 0400Z to 0700Z as well as the varying cloud coverage. The observed detection range at 10 Jan/0300Z was 12.0 nm. Best correlation to this range was the 40,000-ft BLH detection range in Figure 3. Figure 4 shows that when the sensor height (25,000 feet) is above an overcast cloud deck (20,000 feet--see TAF below), the detection range is zero. Figure 4 also shows how the detection range increases as the BLH lowers (or sensor height increases) and departs from the sensor height. The EOTDA forecast (taken from the recorded weather observations from 10 Jan 96/1800Z to 11 Jan 96/1800Z) corresponding with the results in Figures 3 and 4 is given below.

NFL TAF 1818 18006KT 9999 SCT060 BKN120 OVC200 QNH3000INS CIG120
BECMG 0304 33012KT 9999 -SHRA SCT050 OVC090 QNH3010INS CIG090
BECMG 0607 VRB05KT 9999 NSW SCT060 BKN080 BKN200 QNH3030INS CIG080
BECMG 0809 VRB05KT 9999 SCT060 SCT200 QNH3033INS
BECMG 1112 VRB03KT 9999 SCT035 BKN060 BKN080 QNH3036INS CIG060;

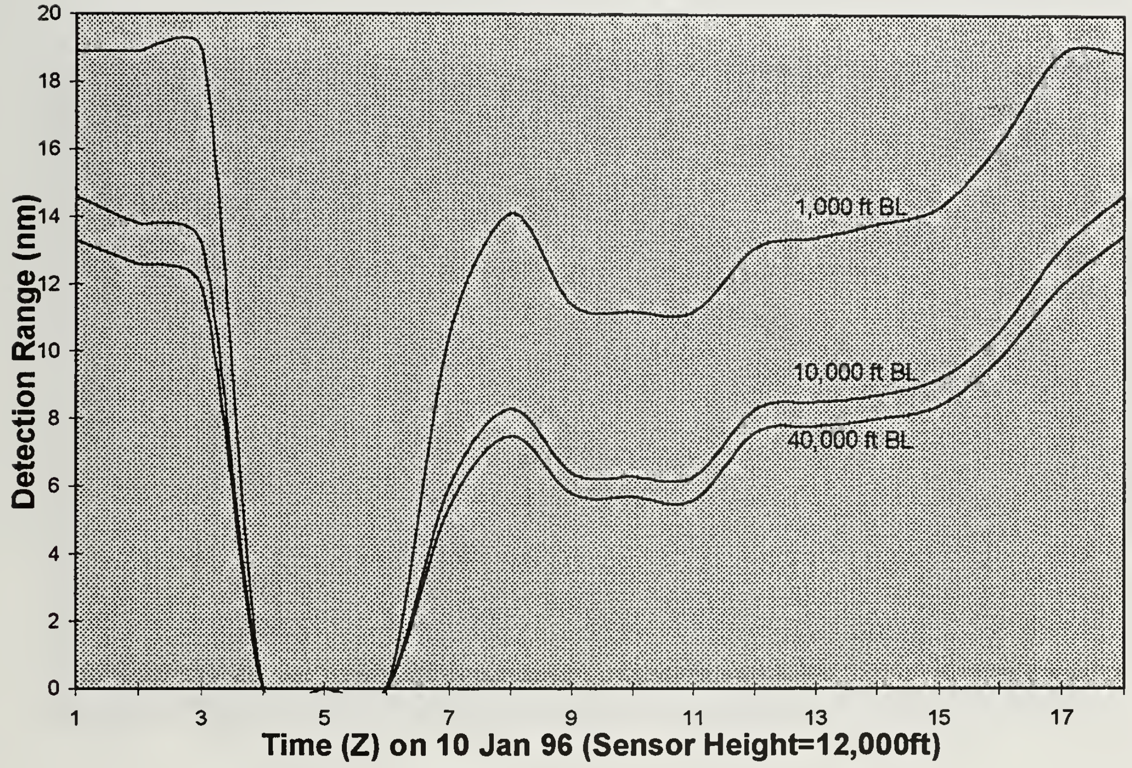


Figure 3. Time series on 10 Jan 96 of detection ranges for boundary layer heights of 1,000, 10,000, and 40,000 feet with the upper layer default applied. Rain showers occurred from 0400Z to 0700Z, and the clouds scattered out by 0900Z. By 1200Z, a 9,000-foot ceiling formed. The sensor height was 12,000 feet.

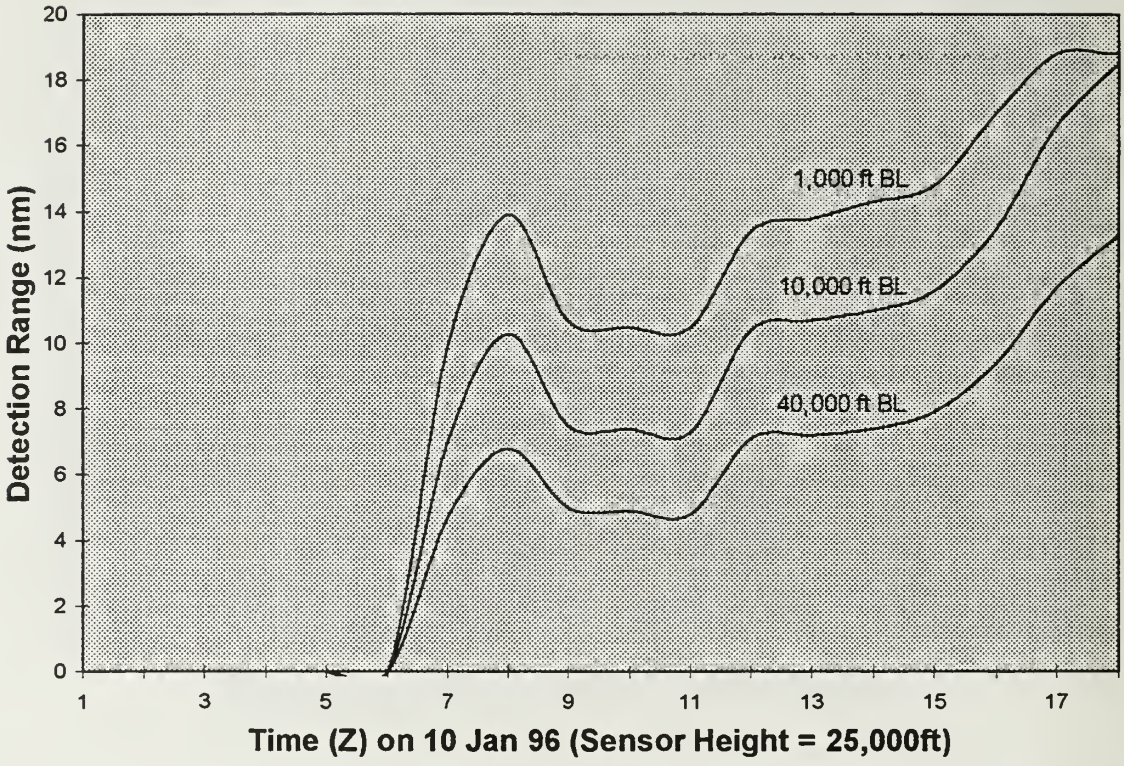


Figure 4. Time series on 10 Jan 96 of detection ranges for boundary layer heights of 1,000, 10,000 and 40,000 feet with the upper layer default applied. All conditions were the same as in Figure 3, except the sensor height was 25,000 feet.

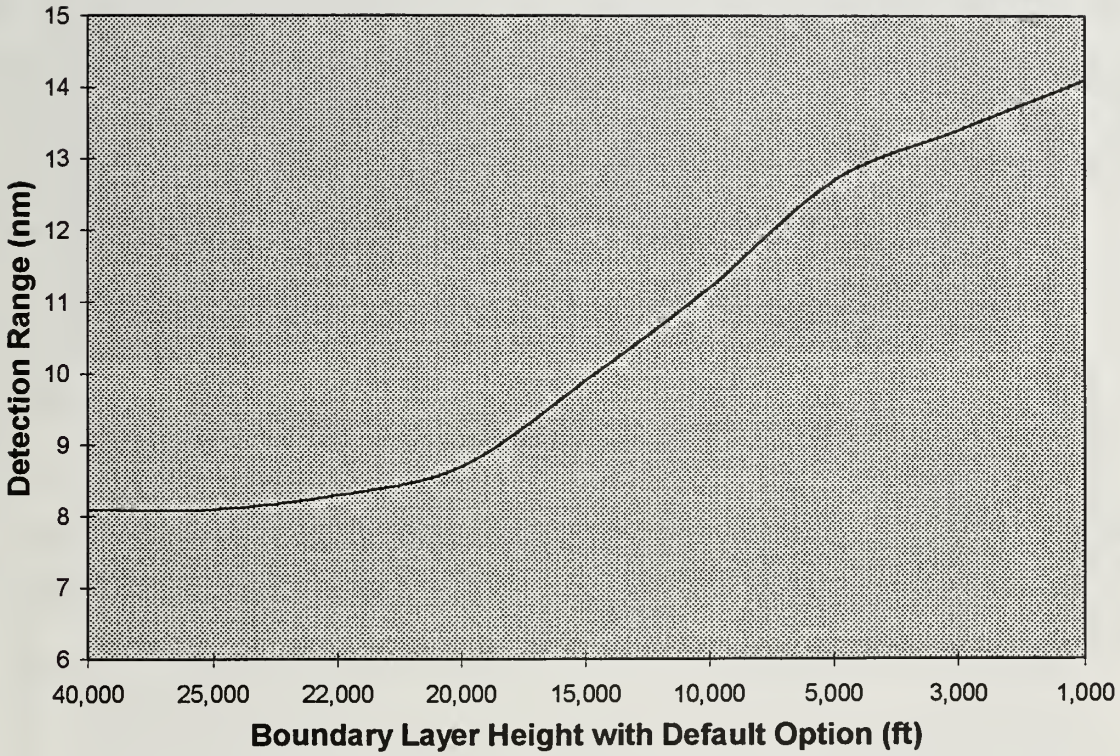


Figure 5. Averaged NFOV MRT detection ranges as a function of boundary layer height using default option on 20 Jan 96/0100Z with the runway target. The sensor height was 23,000 feet. As the BLH departs from the sensor height to 1,000 feet, the detection range increases by six miles.

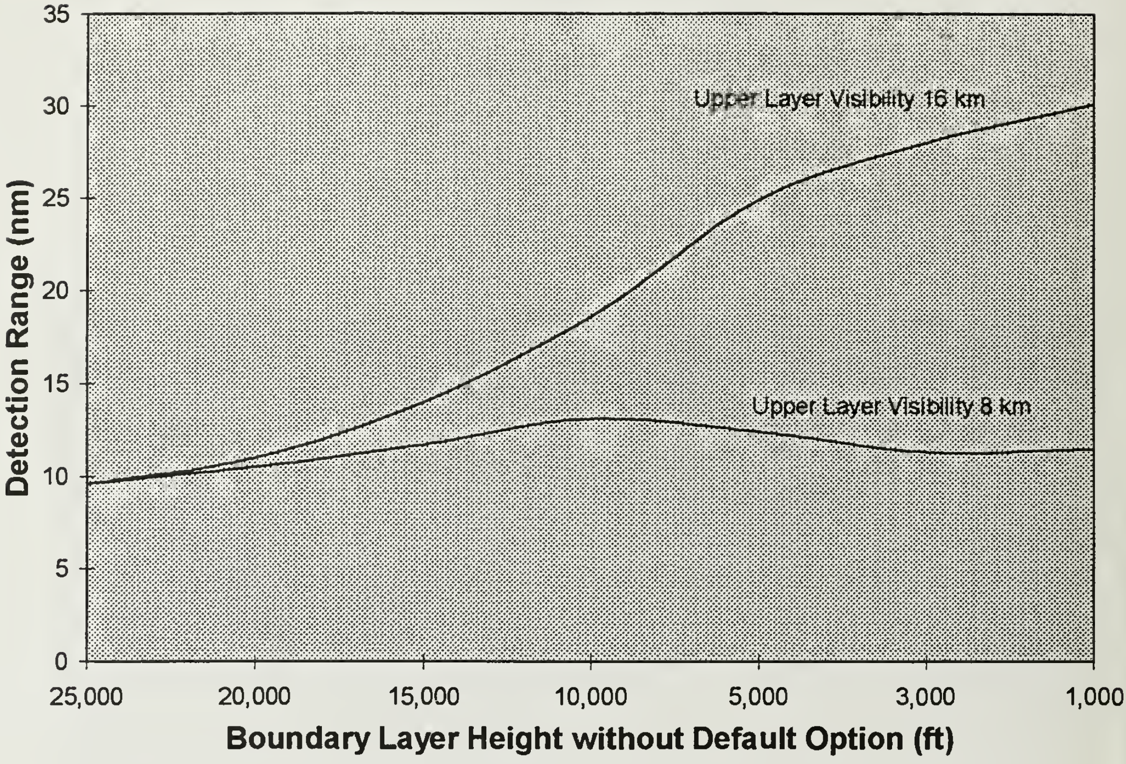


Figure 6. Detection range versus boundary layer height without the default option. The rural aerosol was used with the 8-km upper layer visibility, and the tropospheric aerosol was applied to the 16-km upper layer visibility. The target is the runway with TOT of 1700L hours on 19 Jan 96.

e. Wind

Changing wind direction at varying wind speeds up to 40 knots did not change detection ranges in any view direction for heated and unheated targets, with or without precipitation of any intensity. Wind speed is a significant factor with the desert aerosol. In the wind speed test, the speed is incremented by five knots from zero to ninety knots. The desert, rural, and a NAM (open ocean with moderate wind speed) were tested. All other conditions were kept constant. For a rural aerosol, the detection range decreases an average of 29.6% over a range of zero to 50 knots. From zero to 25 knots, the change is 45.6%; and, from 25 to 50 knots, the percentage decrease is 13.6%. With the desert aerosol, the model did not compute results for speeds greater than 25 knots at a sensor height of 23,000 feet. The speed sharply decreases by 76.4% from zero to 25 knots. A five knot change in wind speed changed the detection range by up to three miles for a rural aerosol and up to six miles for the desert aerosol. Results are illustrated in Figure 7. Both the Navy Maritime and rural aerosols follow a similar trend. In particular, the predicted detection range increased when the wind speed increased from 35 to 40 knots. The delta-T values of 0.3 Kelvin did not change. This increase cannot be explained. The EOTDA User's Manual advises using the desert aerosol in windy conditions.

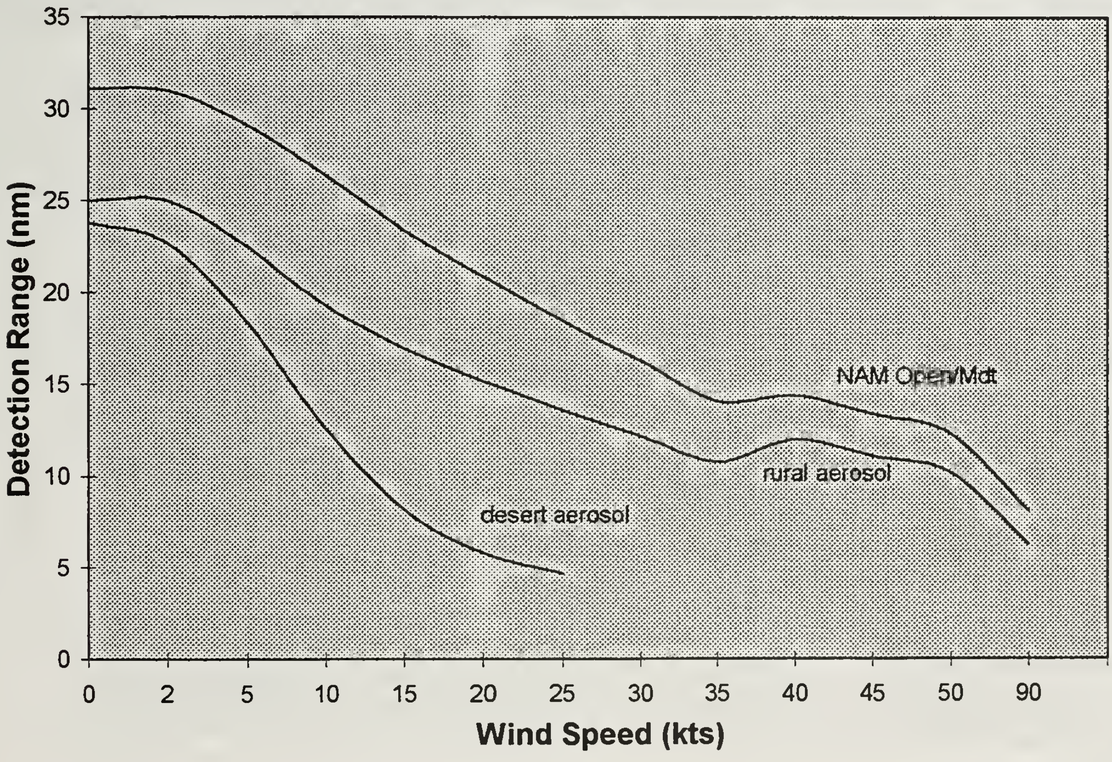


Figure 7. Detection range as a function of wind speed on 20 Jan 96/0100Z with the runway target. Sky condition was clear and visibility was unrestricted.

f. Visibility and Weather

There are 21 weather codes to specify the weather in the TAF. This segment includes the sensitivity analysis of fog and precipitation. The types of weather affecting visibility are categorized as precipitation and obscurations. The baseline EOTDA input is listed in the table below.

	Baseline EOTDA for 20 Jan 96/0100Z
Temperature (°F) (min/max/min)	29/47/29
Dewpoint (°F)	22
Aerosol	Rural
NFL TAF	VRB02KT 9999 SKC with fog, haze, smoke, sand, dust VRB02KT 9999 BKN050 with precipitation 27025KT 9999 SKC with sand storms and dust storms
View Direction	360 degrees
Complexity	None
Target Heading	Runway: 30 degrees Bunker: 270 degrees
Targets	Dry Runway (see Table 3) Dry Bunker (see Table 4)
Albedo	Desert
Background	Concrete: Dry, uncolored parking lot
Boundary Layer Height	40,000 feet
Sensor Height	3,000 feet
Average MRT NFOV Detection Range with unrestricted visibility and no weather (nm)	VRB02KT 9999 SKC: Runway:12.64/Bunker: 12.14 VRB02KT 9999 BKN050: Runway: 12.01/Bunker: 13.03 27025KT 9999 SKC: Runway: 12.40/Bunker: 10.96

Table 13. Baseline conditions for visibility and weather sensitivity study.

With each weather phenomenon, the baseline visibility starts at seven nautical miles (TAF code "9999") and is gradually reduced. Precipitation intensities were also analyzed. Continuous types of precipitation will be discussed first, beginning with drizzle, then rain, then snow. Shower precipitation is discussed next. Finally, obscurations such as fog, haze, smoke, dust, and sandstorms are reviewed.

Figure 8 shows how the detection range decreases with decreasing visibility due to drizzle. Figure 9 illustrates the differences between light, moderate, heavy, and freezing drizzle. Freezing drizzle has unreasonable high detection ranges, similar to those of rain showers. Light drizzle unexpectedly had lower detection ranges than moderate and heavy drizzle. Moderate and heavy drizzle had the same detection ranges.

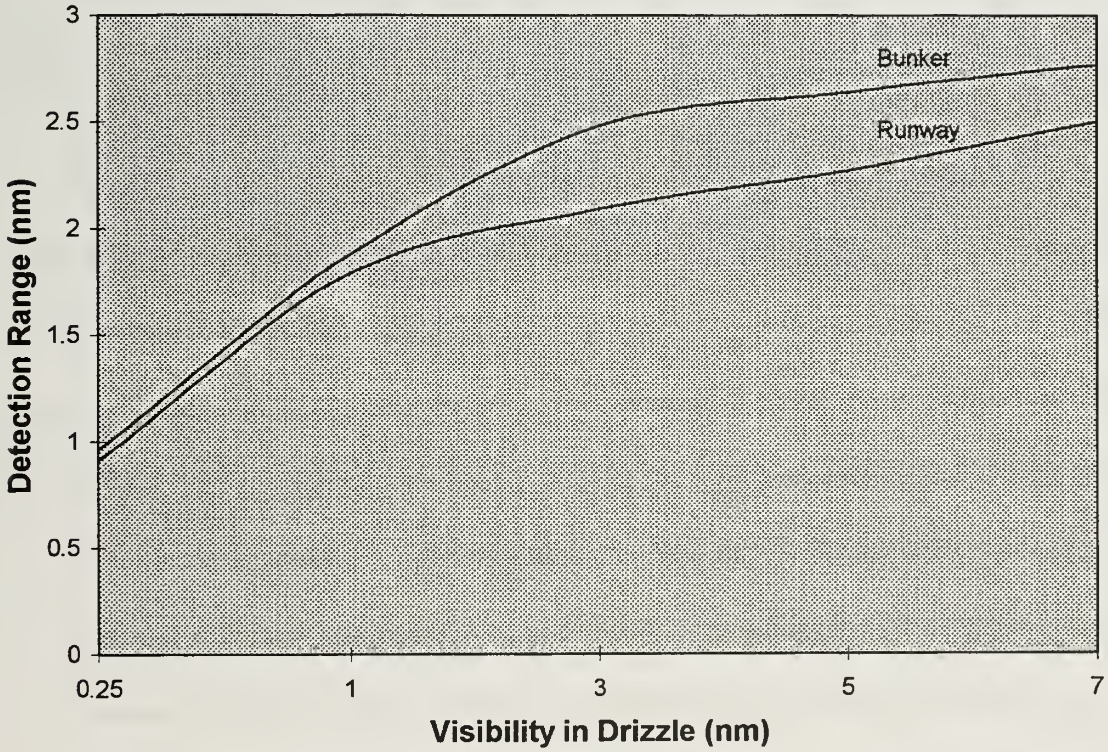


Figure 8. Detection range versus decreasing visibility due to drizzle.

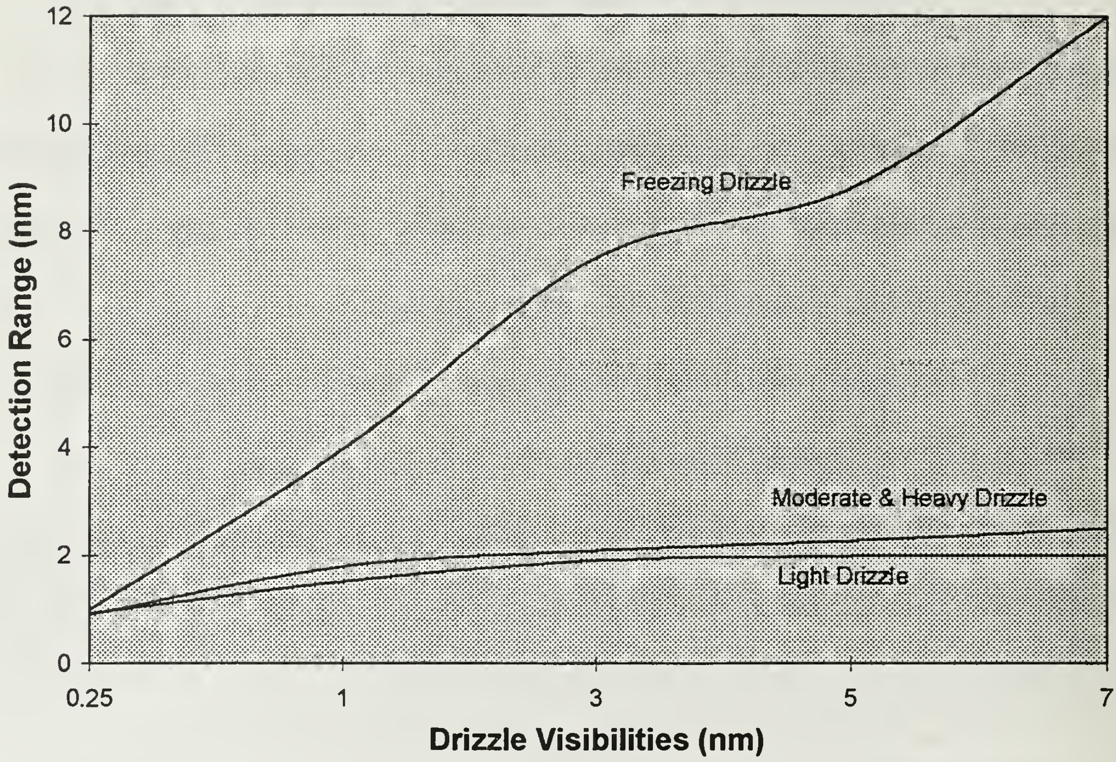


Figure 9. Detection ranges for all types of drizzle and varying visibility with the runway target.

Figures 10 and 11 show continuous rain detection ranges with dry targets and background. Wet targets and wet background reduced the detection ranges by about 17% for the runway and less than 10% for the bunker. Light intensity rain (coded -RA) raised the detection ranges by approximately 10% for the runway and 25% for the bunker. Heavy intensity rain (+RA) gave the same output as moderate rain (RA). The EOTDA User's Manual (1994) states that aerosol extinction due to rain is determined by rainfall rate and is added to the prevailing aerosol extinction. Interestingly, thunderstorms with hail (TAF code TSGR) give the same output as rain (RA). The low detection ranges are reasonable since the rain reduces the target-background temperature contrast to nearly zero (thermal crossover).

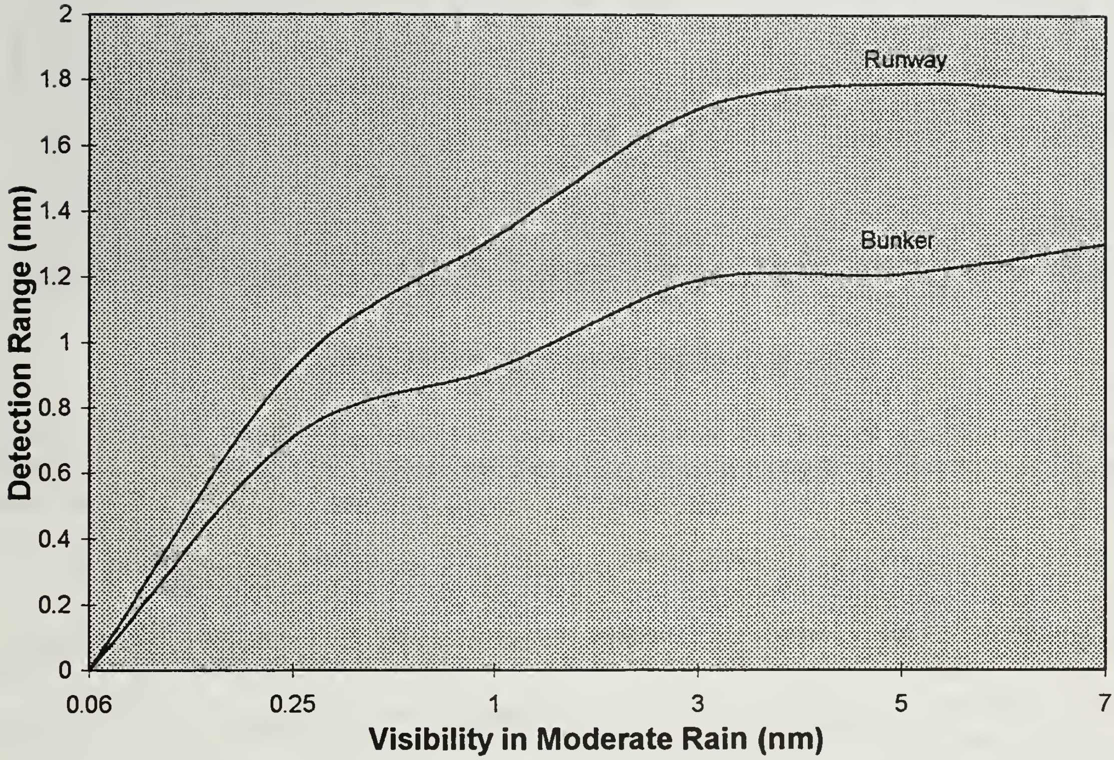


Figure 10. Detection range with moderate rain visibilities.

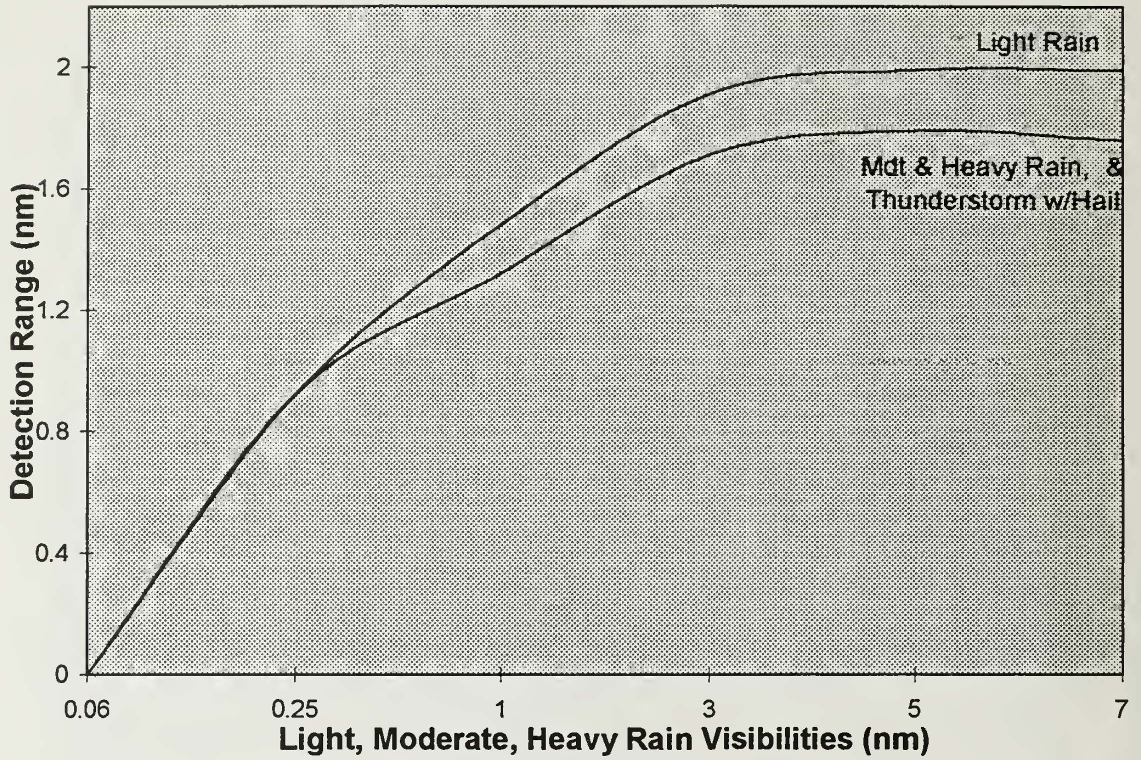


Figure 11. Detection ranges with visibility due to different rain intensities. The EOTDA computes the same detection ranges for thunderstorms with hail.

The next type of continuous precipitation analyzed was snow. Figure 12 illustrates these results. Overall, the detection range decreases 8.5% per mile reduction in visibility. Detection ranges did not change with change of snow intensity. The EOTDA User's Manual (1994) states that for snow, total extinction is scaled on visibility only and the prevailing aerosol extinction is not added. Light snow showers, snow grains, diamond dust, ice pellets, and hail pellets also have the same detection ranges as continuous snow.

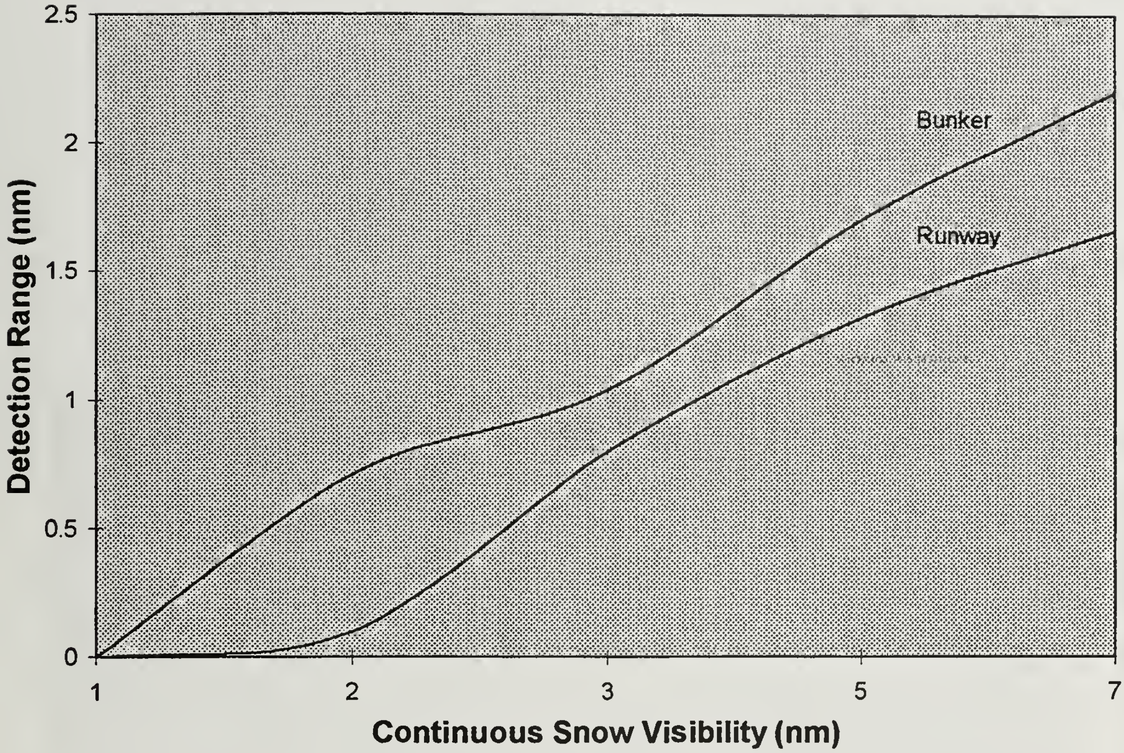


Figure 12. Detection ranges for all intensities of continuous snow, snow grains, light snow showers, ice pellets, hail pellets, and diamond dust.

Rain showers give a much higher detection range than continuous rain--12.0 nm versus 1.76 nm when the visibility is 7 miles; overall, 85% higher (see Figure 13). Freezing rain (coded FZRA) and moderate snow showers (SHSN) had the same ranges as moderate rain showers (SHRA). However, light and heavy rain showers (-SHRA and +SHRA, respectively) had much shorter detection ranges (see Figure 14), different polarity, and the delta-T values were nearly five degrees K cooler than ranges calculated with moderate rain showers. There is an inconsistency in that light and heavy rain showers both had shorter detection ranges than moderate rain showers.

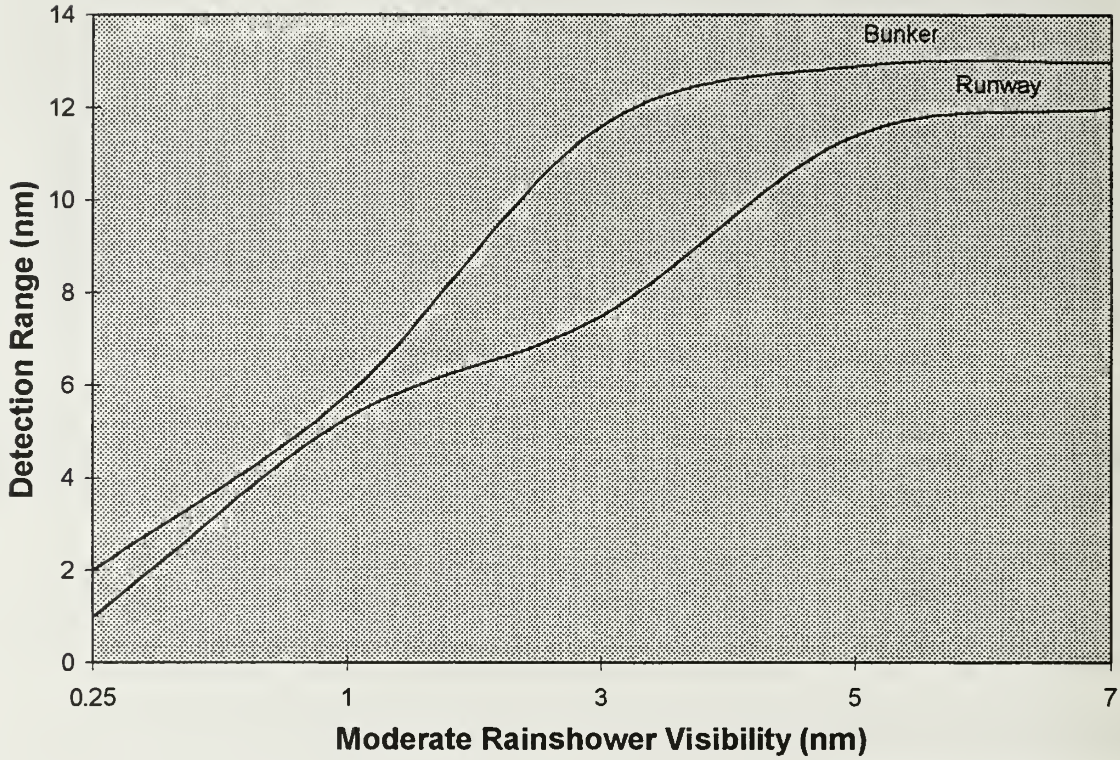


Figure 13. Detection ranges for moderate rain showers for the bunker and runway targets.

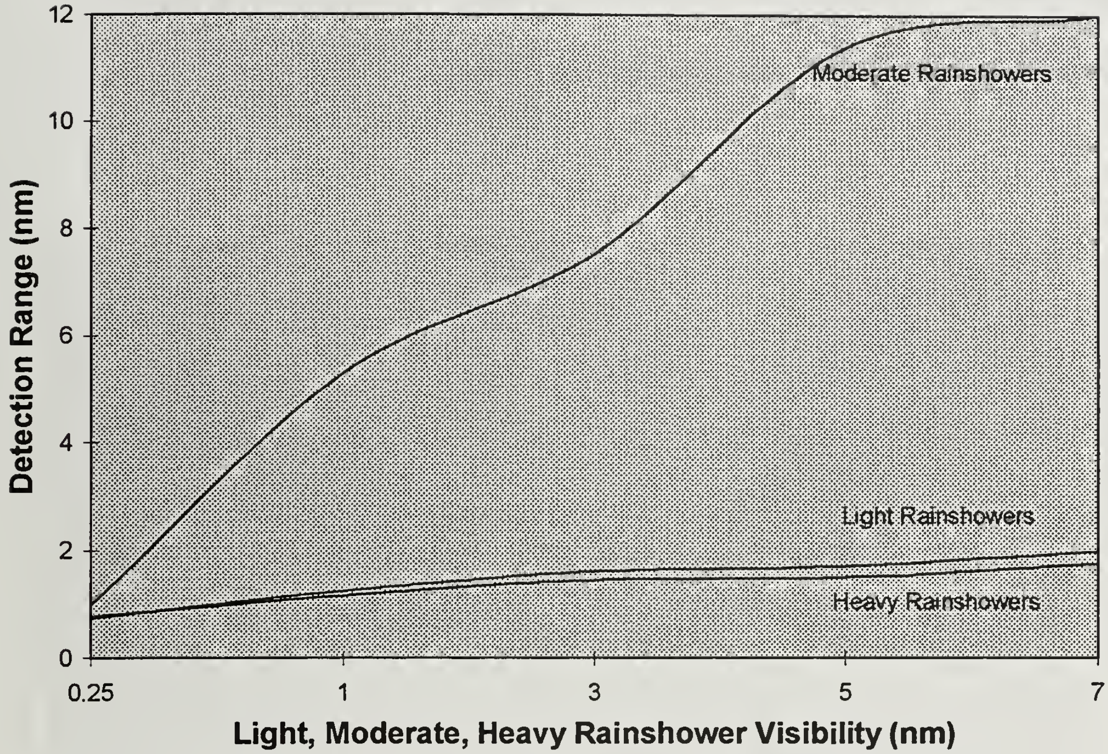


Figure 14. Detection ranges for the runway as a function of visibility and rain shower intensity.

In the fog study, the detection ranges are higher than what operational experience has shown. One reason is the temperature-dewpoint spread was too high in one test case. On 20 Jan 96/0100Z, the recorded temperature-dewpoint spread was 16 °F. To compare the EOTDA results with a realistic temperature-dewpoint spread, another case was run with a 2 °F spread. Figures 15 and 16 show the detection ranges when the temperature-dewpoint spread is 16 and 2 °F, respectively. Figure 17 illustrates this comparison. The average difference in these detection ranges is 27%. In both cases, the runway was colder than the background with an average delta-T of -1.4 K. The bunker detection ranges and delta-T values varied more with view direction than the runway values. The bunker delta-T values ranged from -1.1 K to +17.0 K, and the detection ranges varied from just under 4 nm to 10 nm.

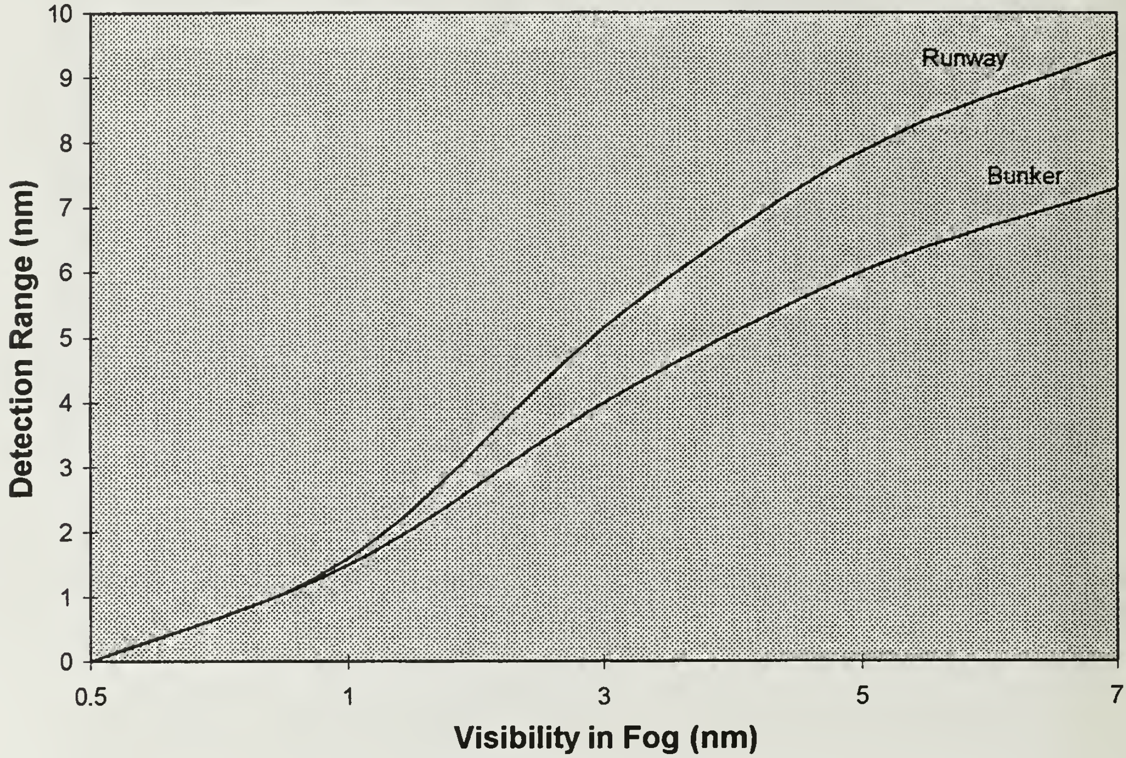


Figure 15. Detection range versus decreasing visibility in fog at 20 Jan 96/0100Z. The temperature-dewpoint spread in the EOTDA was 16 degrees °F.

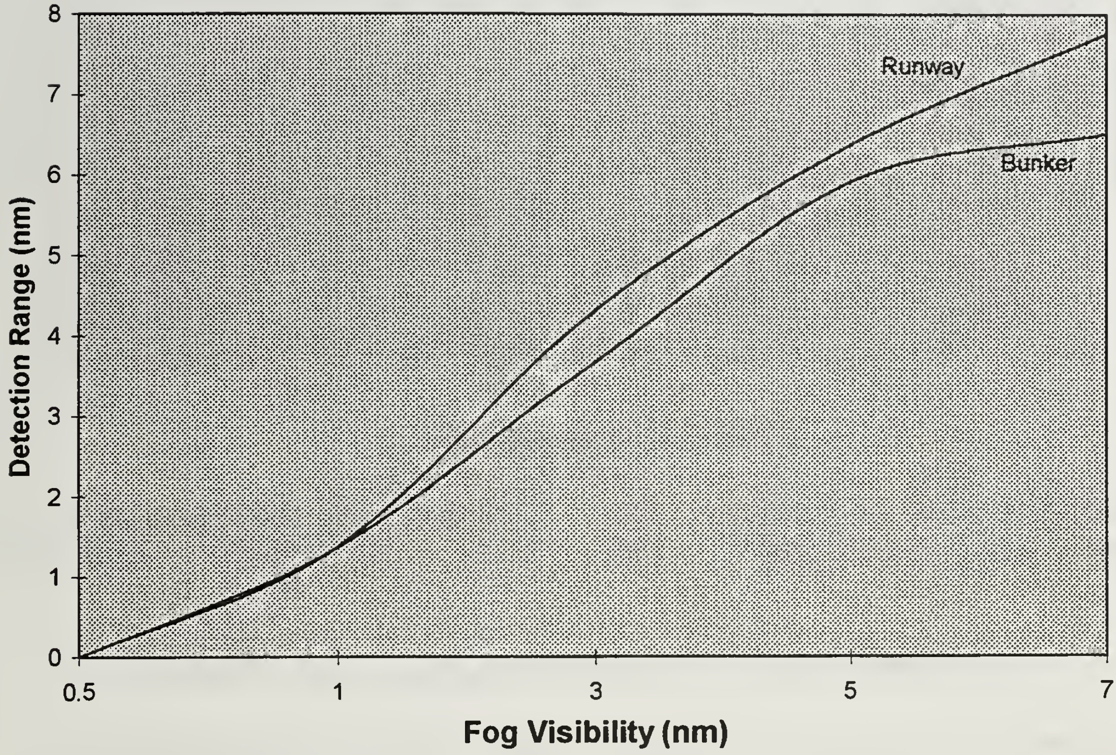


Figure 16. Detection ranges with fog on 20 Jan 96/0100Z with temperature-dewpoint spread of 2 °F.

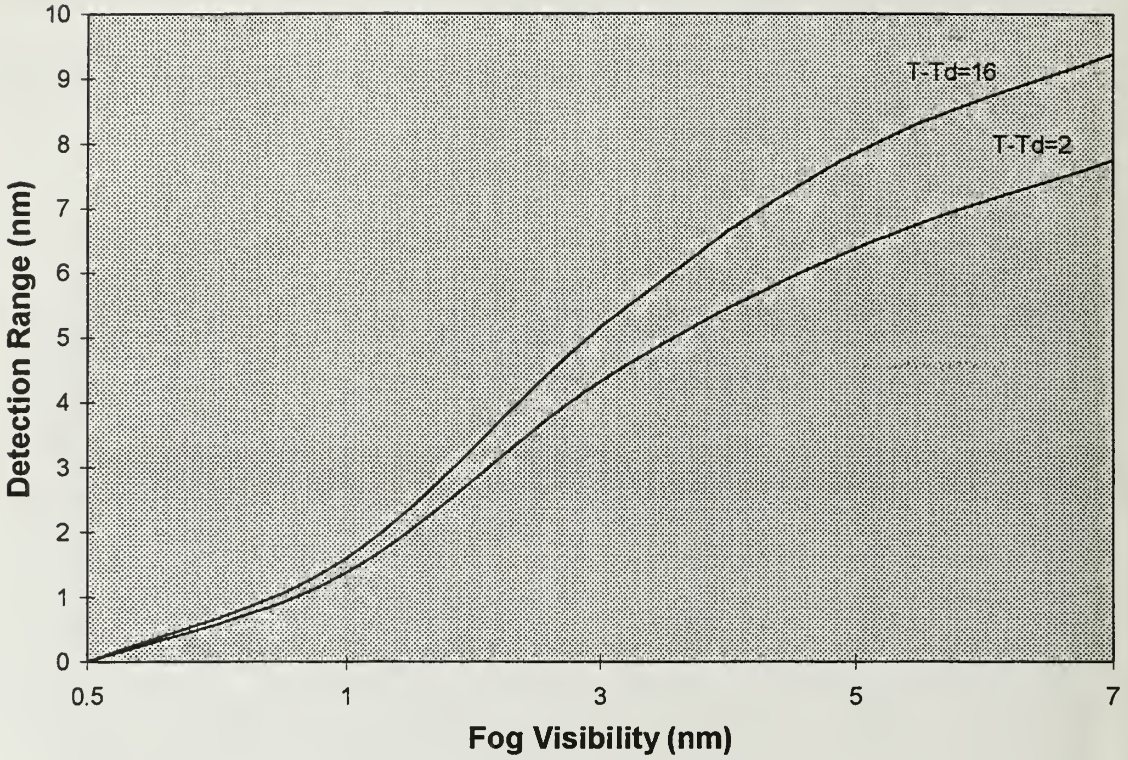


Figure 17. Comparison of detection ranges with 2 °F and 16 °F temperature-dewpoint spreads with the runway target.

The lithometeors are now examined: haze, sand, smoke, volcanic ash, widespread dust, sand storm, and dust storm. Figure 18 illustrates the haze detection ranges. Unrestricted visibility (TAF code 9999) with and without haze gives the same output. A dramatic decrease in detection range occurs when the visibility drops below three miles. The average percentage decrease from seven to three miles is 7%; 50% from three miles to one mile; and 68.5% from one mile to one fourth mile.

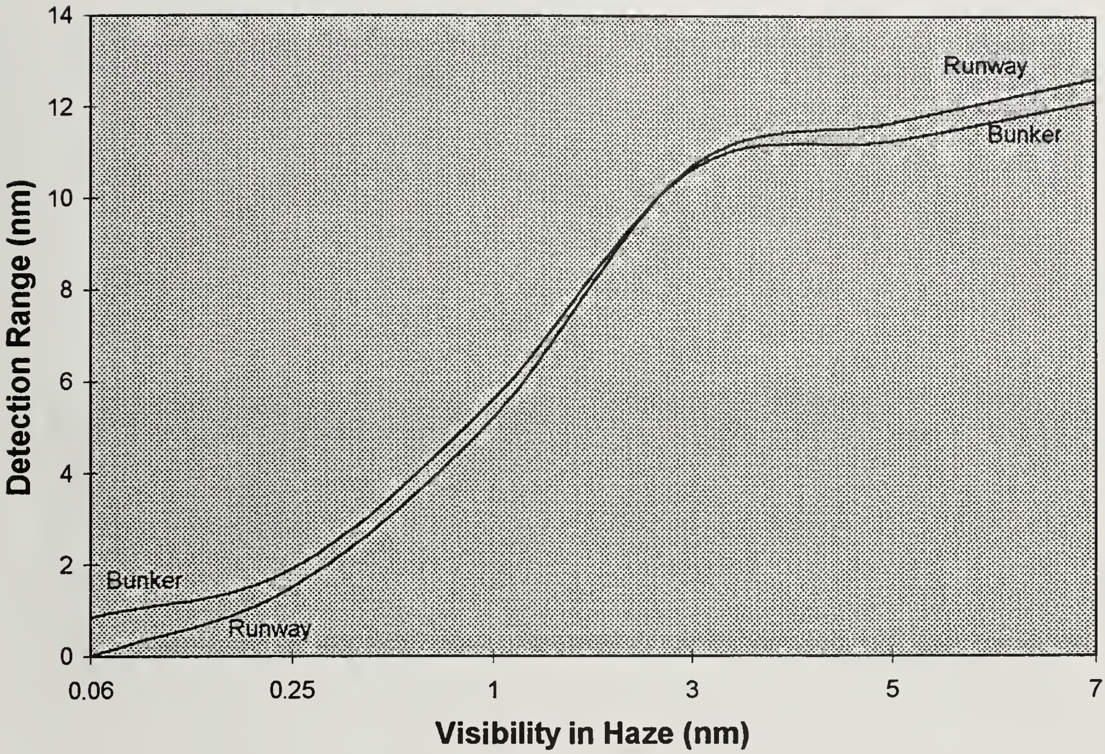


Figure 18. Detection ranges with haze obstructing the visibility.

Figures 19 and 20 illustrate the sensitivity of sand for winds VRB02KT (variable wind direction with two knots speed) and 27020KT (westerly winds at 20 knots), respectively. In comparing Figures 18 and 19, haze and sand have similar detection range trends. Figure 21 compares the runway detection ranges with both wind speeds. The sharpest increase in detection range occurs from one to four miles visibility.

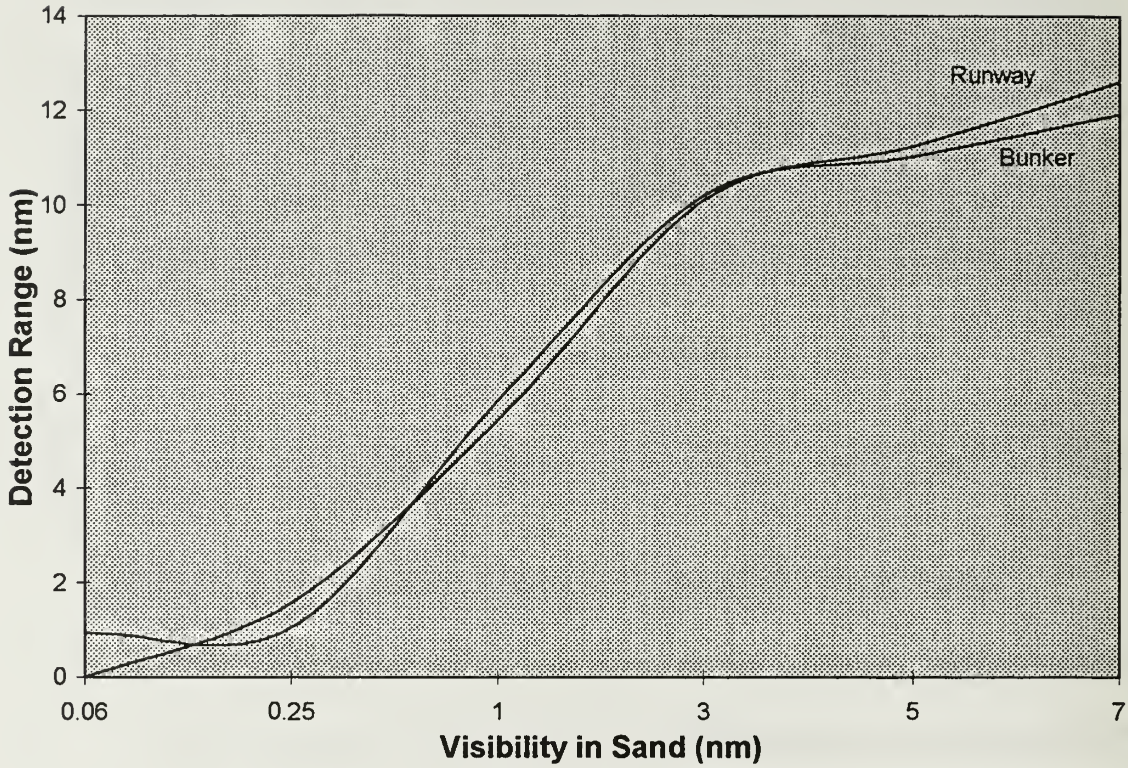


Figure 19. Detection range as function of sand with wind VRB02KT and rural aerosol.

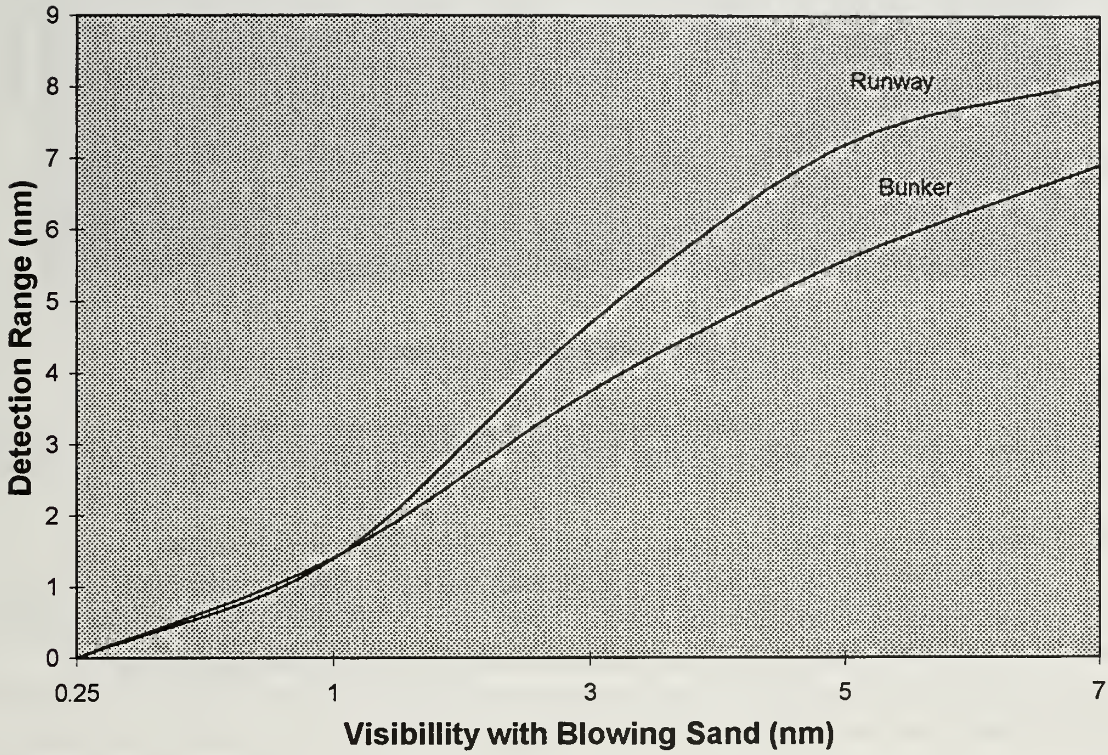


Figure 20. Detection range as function of sand. Winds were 27020KT with rural aerosol.

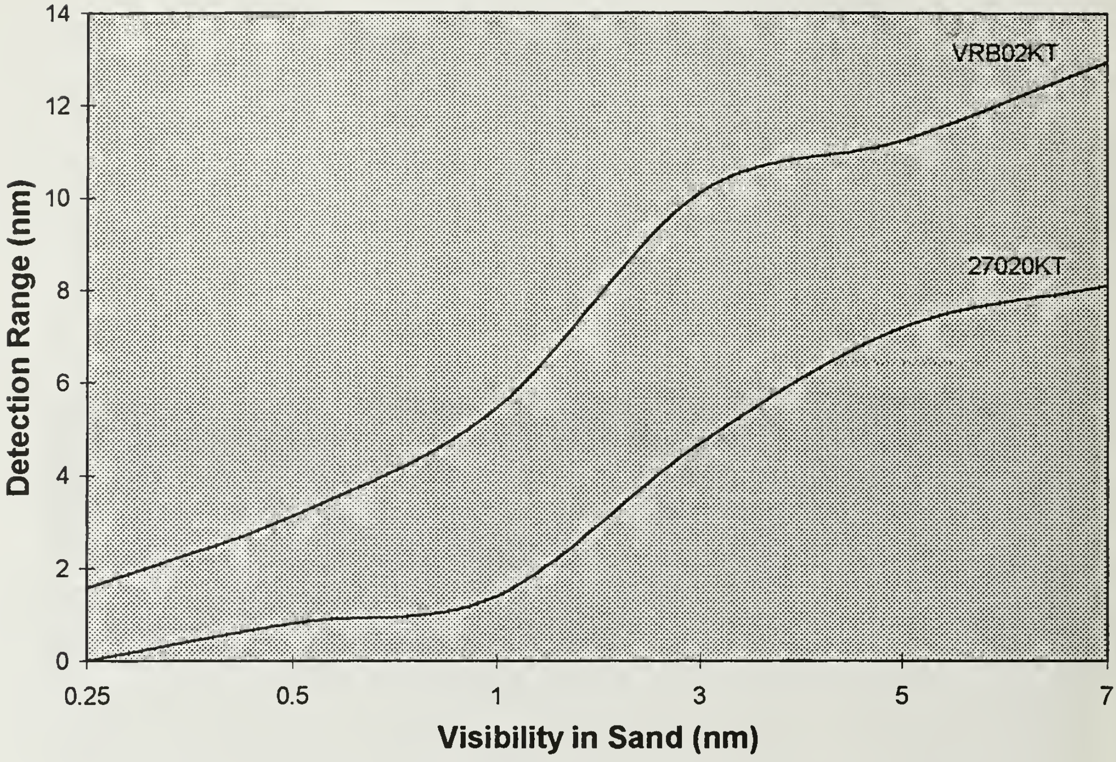


Figure 21. Comparison of detection ranges due to sand with winds VRB02KT and 27020KT.

Sandstorms and duststorms were analyzed next. Both had the same results as sand. The remaining lithometeors are smoke, volcanic ash, and widespread dust. Detection ranges are the same for all three (see Figure 22). When the visibility decreased below three nautical miles, the detection ranges decreased at a faster rate, similar to haze and sand.

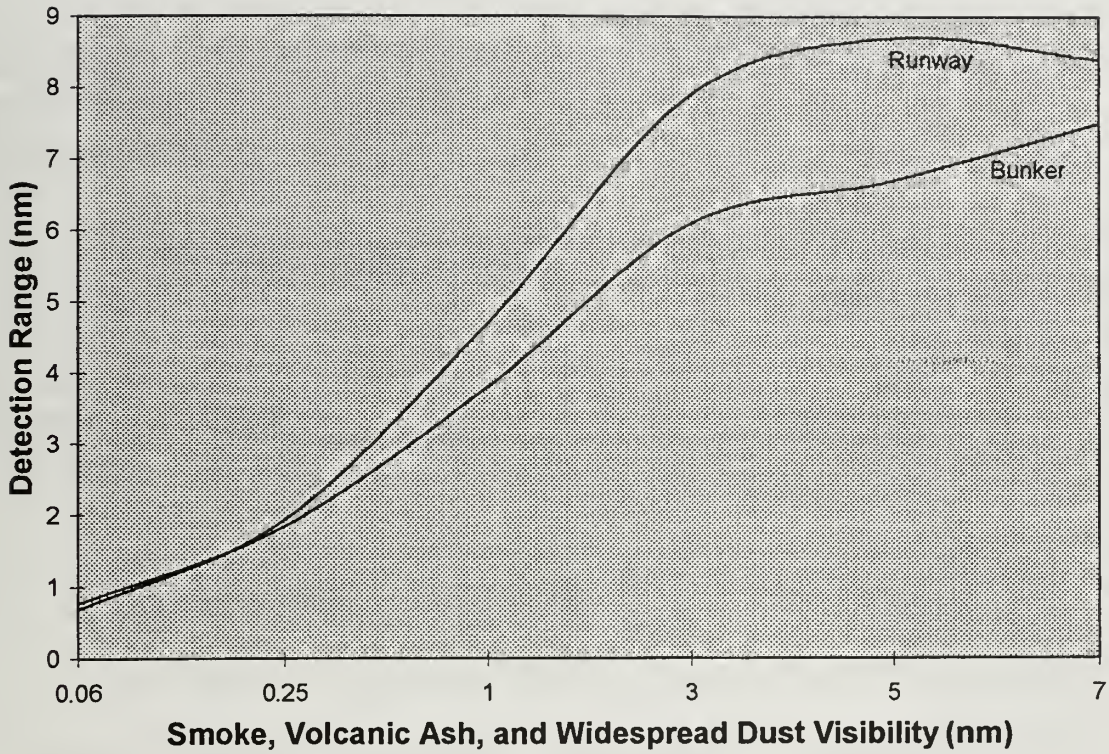


Figure 22. Detection ranges with smoke, volcanic ash, and widespread dust.

Tables 14 and 15 summarize runway target detection ranges for the various hydrometeors and lithometeors, respectively. All hydrometeors, including fog, follow the precipitation TAF in Table 13. The lithometeors in Table 15 follow the TAF with clear skies and light, variable winds.

The EOTDA apparently did not recognize the "+" sign for heavy continuous precipitation. Moderate rain showers and moderate snow showers did not follow the trends of light and heavy showers. Detection ranges in the first two categories seem too long; however, the temperature-dewpoint spread was 16 °F.

	VISIBILITIES (NM)			
RUNWAY DETECTION RANGES (nm) for:	**7**	**5**	**3**	**1**
Freezing Rain (FZRA) Moderate Rain shower (SHRA)	12.0	11.4	7.5	5.3
Freezing Drizzle (FZDZ) Moderate Snow shower (SHSN) Thunderstorm (TS)	12.0	8.8	7.5	4.0
Fog/Mist (FG/BR)	4.9	3.9	2.3	0.6
Moderate Drizzle (DZ) Heavy Drizzle (+DZ)	2.5	2.3	2.1	1.8
Light Rain (-RA) Light Drizzle (-DZ)	2.0	2.0	1.9	1.5
Light Rain shower (-SHRA)	2.0	1.7	1.6	1.3
Moderate Rain (RA) Heavy Rain (+RA) Thunderstorm with Hail (TSGR)	1.8	1.8	1.7	1.3
Heavy Rain shower (+SHRA)	1.8	1.5	1.4	1.2
Light Snow shower (-SHSN) Heavy Snow shower (+SHSN) Light Snow (-SN) Moderate Snow (SN) Heavy Snow (+SN) Snow Grains (SG) Ice Pellets (PE) Hail Pellets (GS) Diamond Dust (IC)	1.7	1.3	0.8	0.0

Table 14. Runway target detection ranges for hydrometeors with varying visibility.

	VISIBILITIES (NM)			
RUNWAY DETECTION RANGES (nm) for:	**7**	**5**	**3**	**1**
Haze (HZ) Sand Storm (SS) Dust Storm (DS)	12.6	11.7	10.7	5.8
Sand (SA)	12.6	11.2	10.1	5.5
Smoke (FU) Volcanic Ash (VA) Widespread Dust (DU)	8.4	8.7	7.9	4.8

Table 15. Runway target detection ranges for lithometeors with varying visibility.

g. Clouds

Figure 23 shows that low clouds significantly reduced the detection range. Scattered clouds at 1,000 feet reduced the detection range more than broken clouds at 20,000 feet. Middle cloud ceilings were also significant. Because the EOTDA assumes a cloud-free line of sight, detection ranges can be expected to be too high with broken cloud ceilings if the pilot must fly in and out of clouds. When the sensor height is above an overcast deck, no solutions are computed.

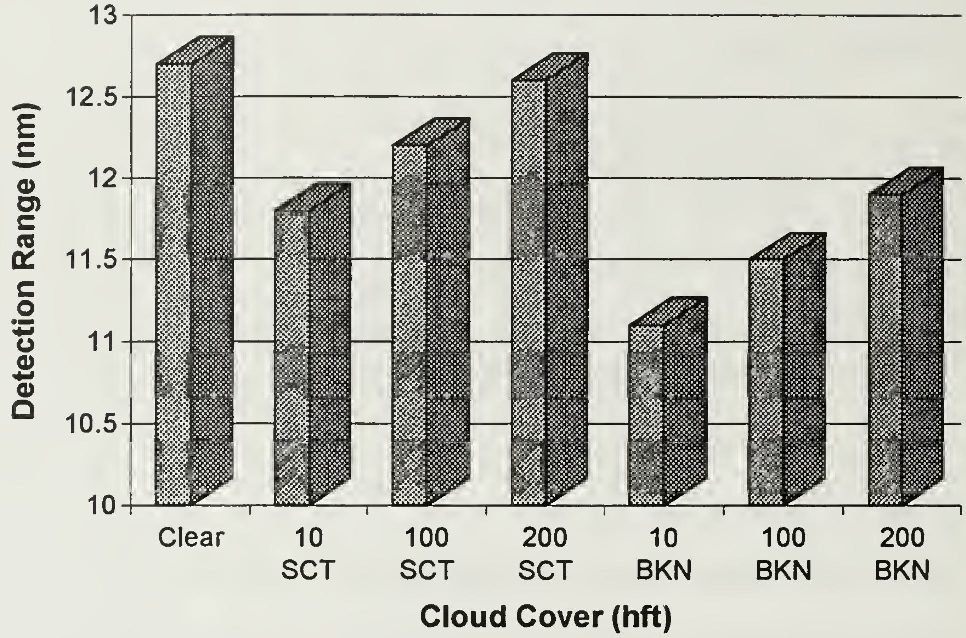


Figure 23. Detection range versus cloud cover with sensor height at 23,000 feet on 19 Jan 96/0100Z.

3. Operational Parameters

a. View Direction

View direction is important during daylight hours since, with solar elevation, solar azimuth angle, and target orientation, it determines the target sensor target geometry. The detection ranges for the bunker in Figure 24 are consistent with the solar elevation and azimuth. With the sun at the pilot's back, detection ranges are longest; going into the sun the target detection ranges are shortest. In Figure 25, the view direction curve is different for the runway target, because of the runway's length compared to its width. The order of longest to shortest detection range cannot be explained in Figure 25. The delta-T value was highest at 2000Z, absolute humidity was highest at 1900Z and lowest at 2100Z. These results show the importance of the relative target dimensions to the detection range.

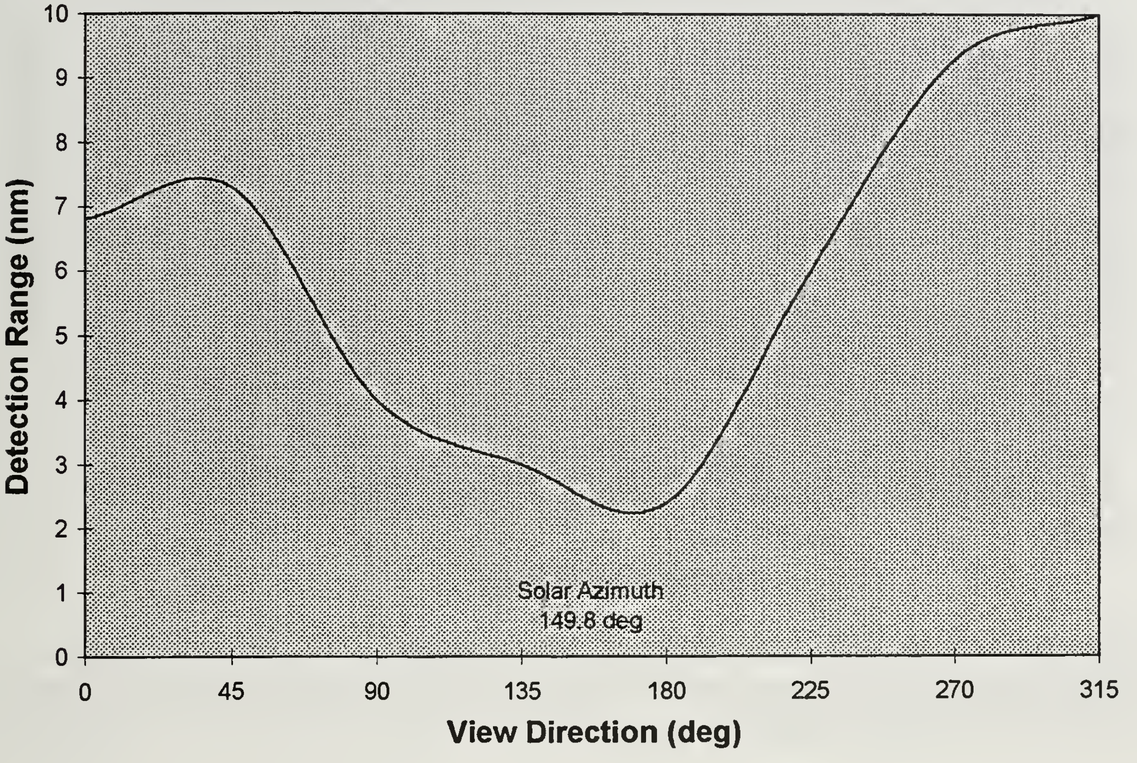


Figure 24. Detection range as a function of view direction on 10 Jan 96/1800Z (1000L) for the bunker target. The solar elevation and azimuth were 22.6 and 149.8 degrees, respectively.

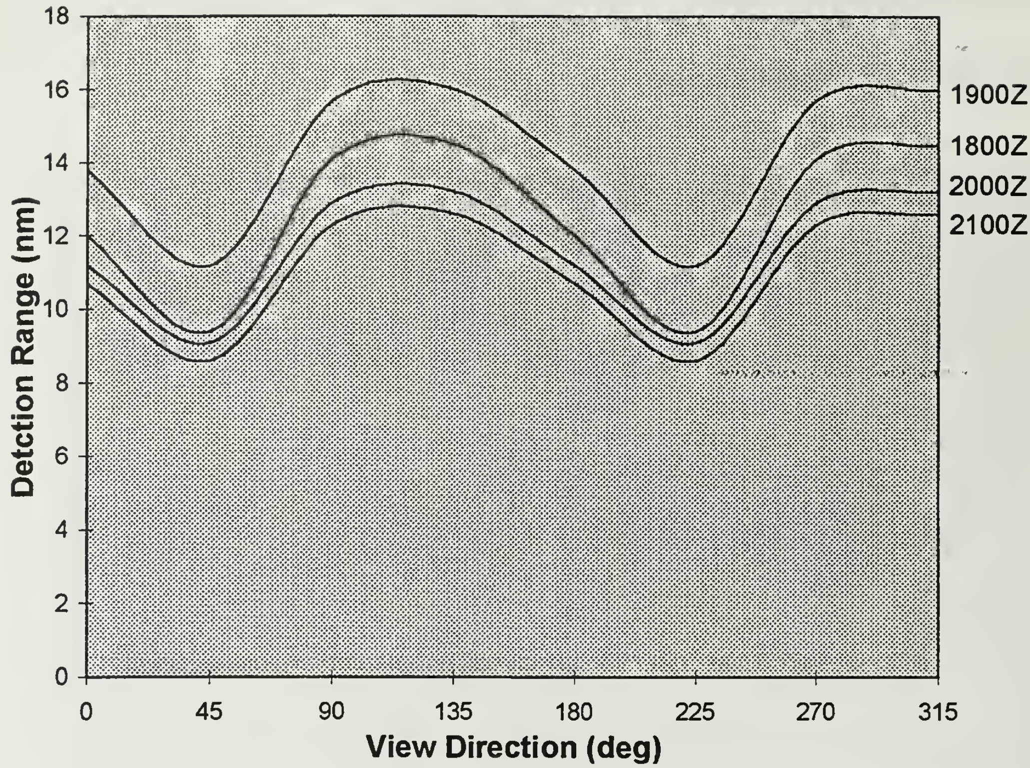


Figure 25. Runway detection range versus view direction on 19 Jan 96 from 1800Z to 2100Z. The solar elevation and azimuth during this time period ranged from 23.8 to 29.0 degrees and 148.3 to 195.1 degrees, respectively.

b. Sensor Height

Target detection range may either decrease or increase with increasing sensor height depending on the target (see Figure 26). The runway detection range increases slightly from 5,000 feet to 8,000 feet, then decreases steadily. The bunker detection ranges decrease at a slower rate. Greater cloud coverage could be attributed to this slower change. In general, EOTDA detection ranges decrease with increasing sensor height.

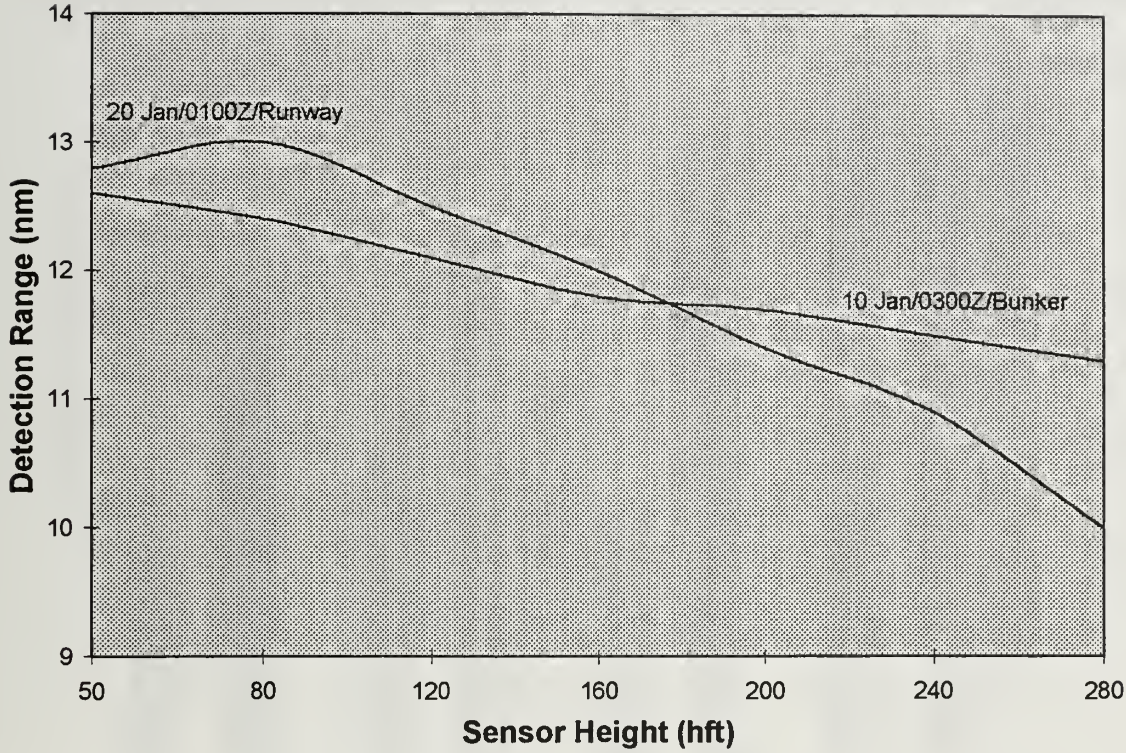


Figure 26. Detection range versus sensor height for the runway and bunker. There is no cloud ceiling on 20 Jan 96 at 0100Z. On 10 January at 0300Z, the ceiling is broken at 12,000 feet.

c. *Complexity*

Complexity is defined as the "busyness" of the target scene. It describes the number of objects or patterns in the immediate target area that can be mistaken for the target. An example of a highly complex scene is the bunker target in the bombing range near NAS Fallon. There are 32 bunkers in that specific target area, making it difficult for the pilot to choose or select a specific bunker. However, the degree of complexity selected (none, low, medium, or high) in the EOTDA had little or no effect on the detection range (see Figure 27). The difference was less than one half nautical mile between the "none" and "high" complexities. There was no difference between the "low" and "medium" complexities.

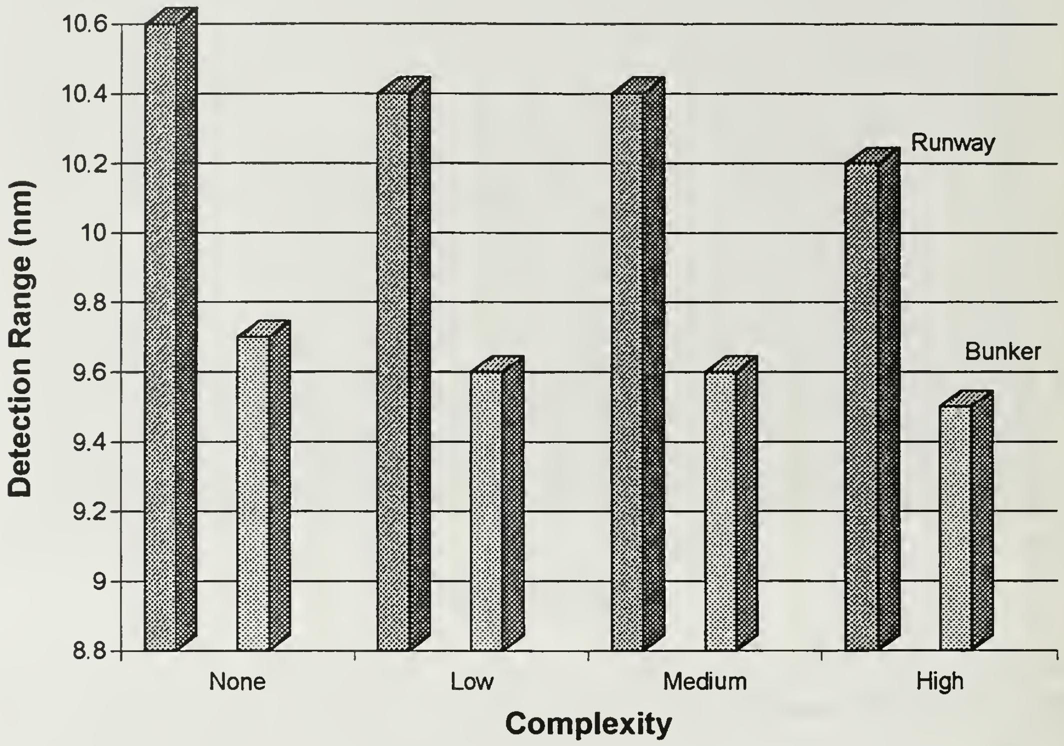


Figure 27. Detection range versus target scene complexity on 10 and 20 Jan 96 with the bunker and runway targets, respectively.

d. Targets

Detection ranges for some of the standard targets are compared in Figure 28. The EOTDA ranges for different targets vary from 7 nm for a tank to 26 nm for a power plant and bridge. This is strictly related to target dimension, which determines sensor angular subtense.

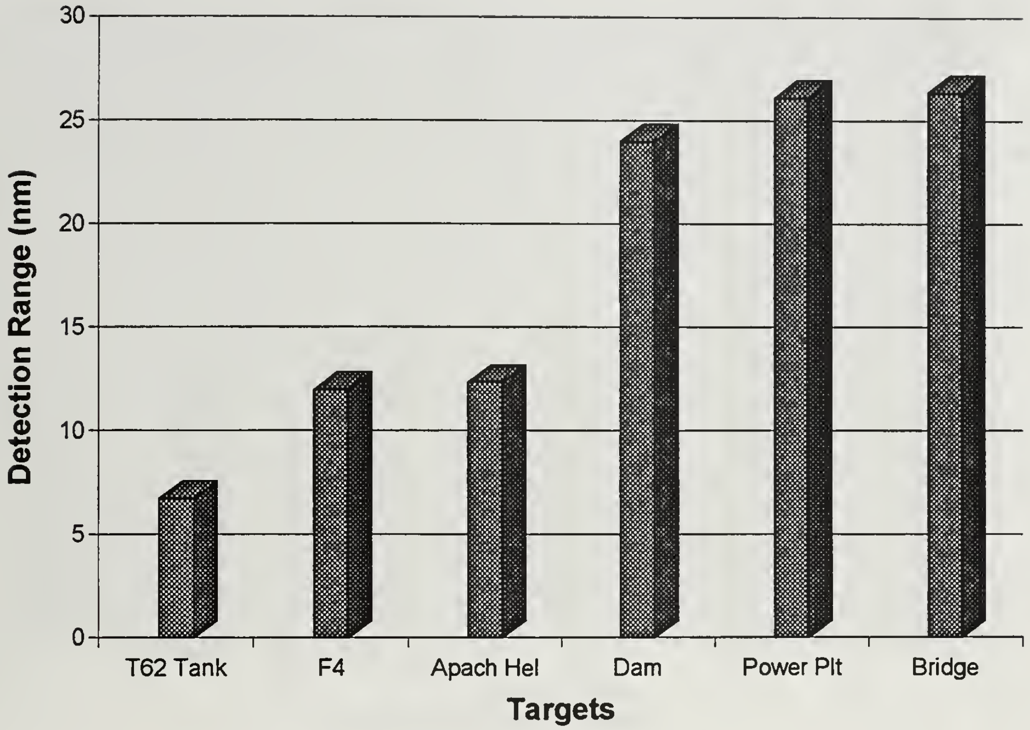


Figure 28. Comparison of detection ranges with some of the standard EOTDA targets.

e. Target Heading

The target heading is the direction the front of the target is facing. For example, the EOTDA user enters 90 degrees if the front of the target is facing east. The heading is a reference in computing some of the target parameters, such as apparent target size, viewable target facets, heating, and shadow size (Gouveia *et al.* 1994). The electro-optic forecaster must get target heading information from the intelligence analysts. In this test, target heading in the EOTDA was not a significant factor for the bunker detection range (see Figure 29).

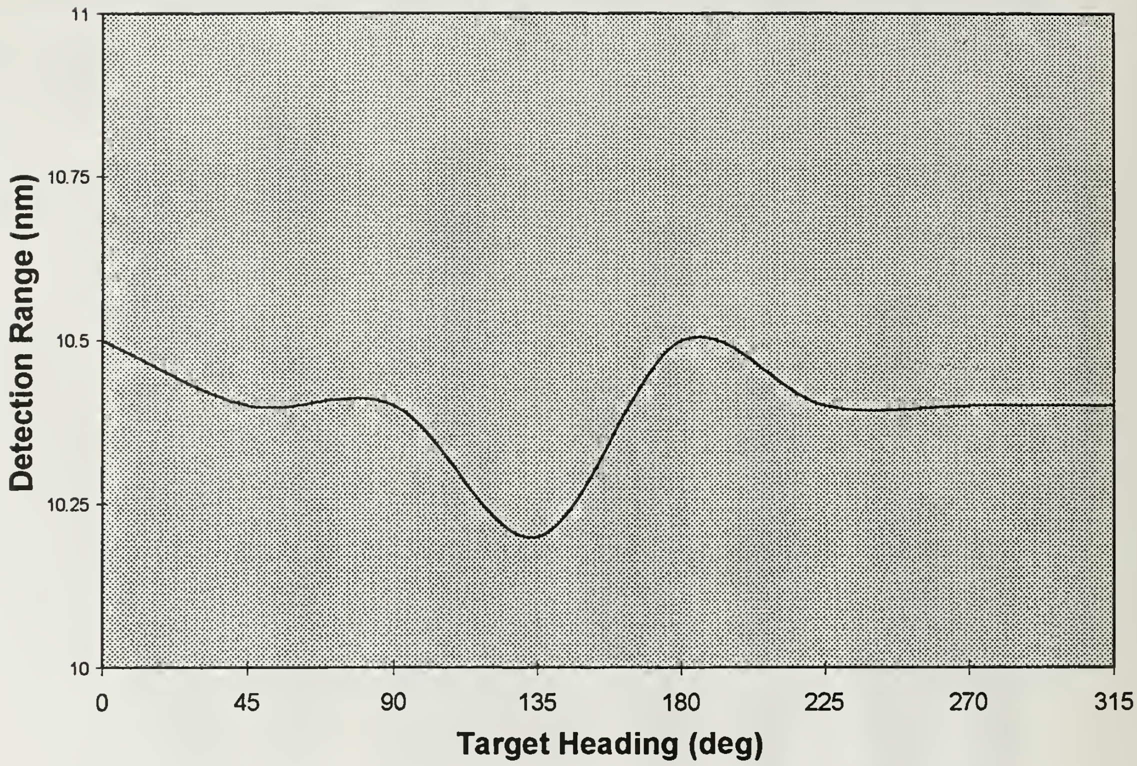


Figure 29. Detection range versus target heading for the bunker target on 10 Jan 96/0300Z.

f. Albedo

Albedo in the EOTDA describes the general target area reflectivity. There are five choices of albedo: continental, urban, desert, ocean, and snow. Results in Figure 30 show that target areas with the highest albedo are predicted to yield the longest detection range. Snow yields the longest range and ocean yields the shortest. The difference between snow and ocean in this case with the bunker target was 1.6 nm, a 14% difference.

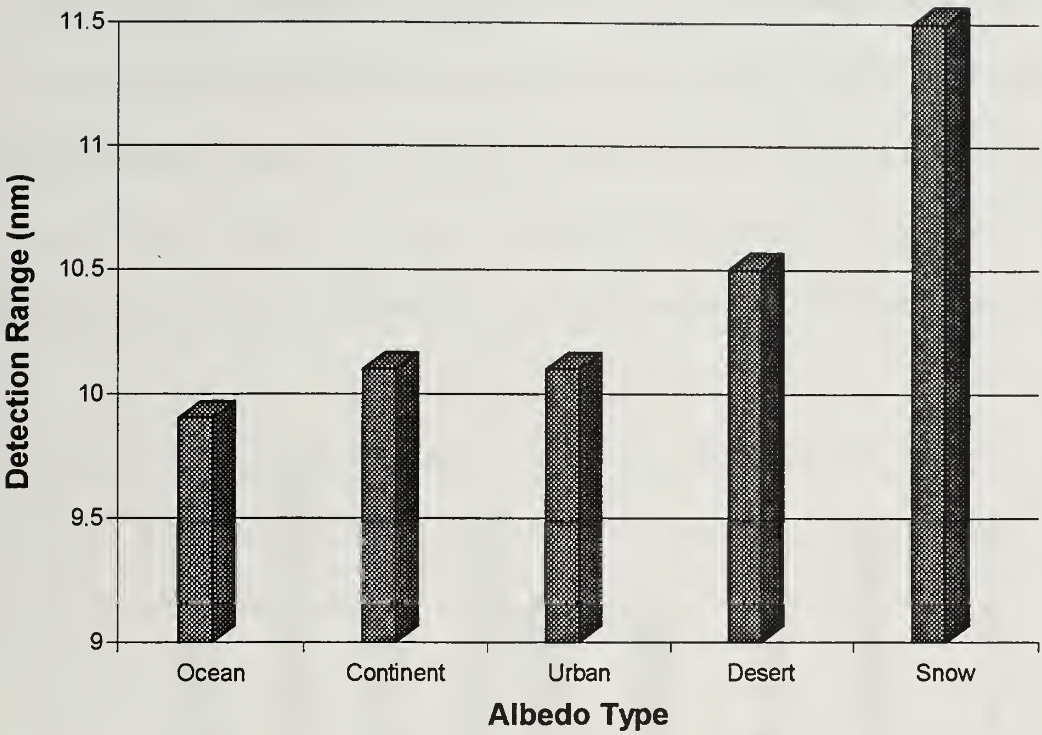


Figure 30. Detection range versus albedo type on 10 Jan 96/0300Z for bunker target.

g. Backgrounds

EOTDA backgrounds are the immediate types of backgrounds or surface materials surrounding the target. The model has eight backgrounds from which to choose, and each has two to three sets of parameters to further specify type, moisture, coverage, depth, or condition. The eight types of backgrounds are: vegetation, soil, snow, water, concrete, asphalt, swamp, and rocky field. The backgrounds were compared with each other, and each background was analyzed within itself to see how much the detection range changes as you vary the specifics of each. Figures 31 and 32 compare the average detection ranges for each background with the bunker and runway targets, respectively. Concrete gave the shortest detection range with the bunker, while the runway's shortest range was with an asphalt background. Snow and water backgrounds yielded similar detection ranges with the bunker, but a four nautical mile difference with the runway. Detection ranges are similar for both targets with the water and asphalt backgrounds, but significant differences with the other backgrounds. Figures 33 through 36 show how detection range is affected as the parameters for each particular background are changed.

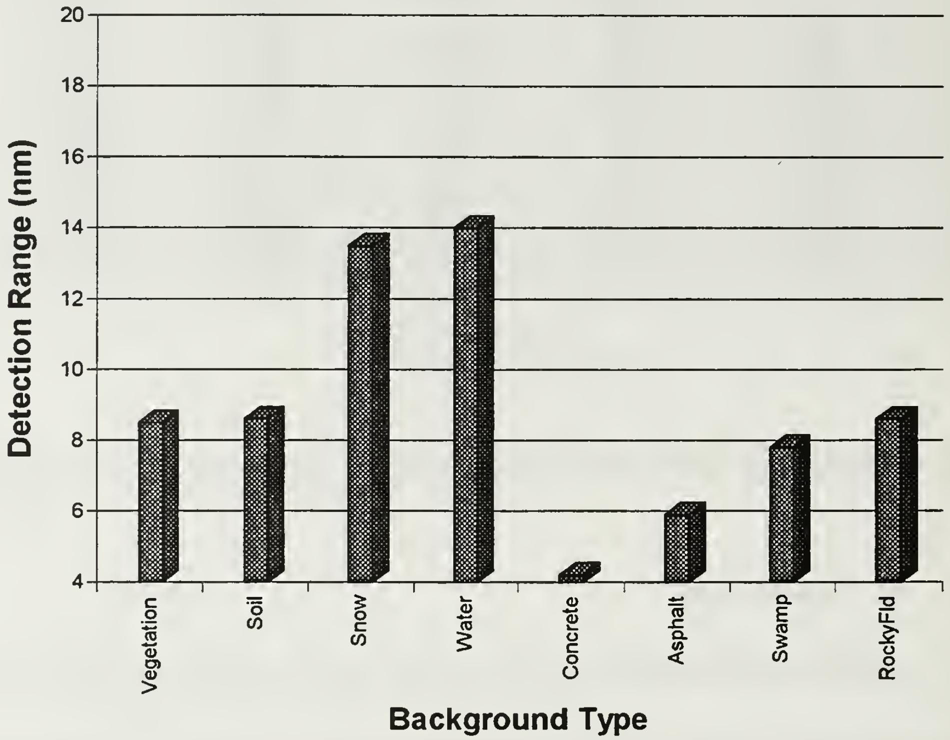


Figure 31. Detection range versus background on 10 Jan 96/0300Z with bunker target.

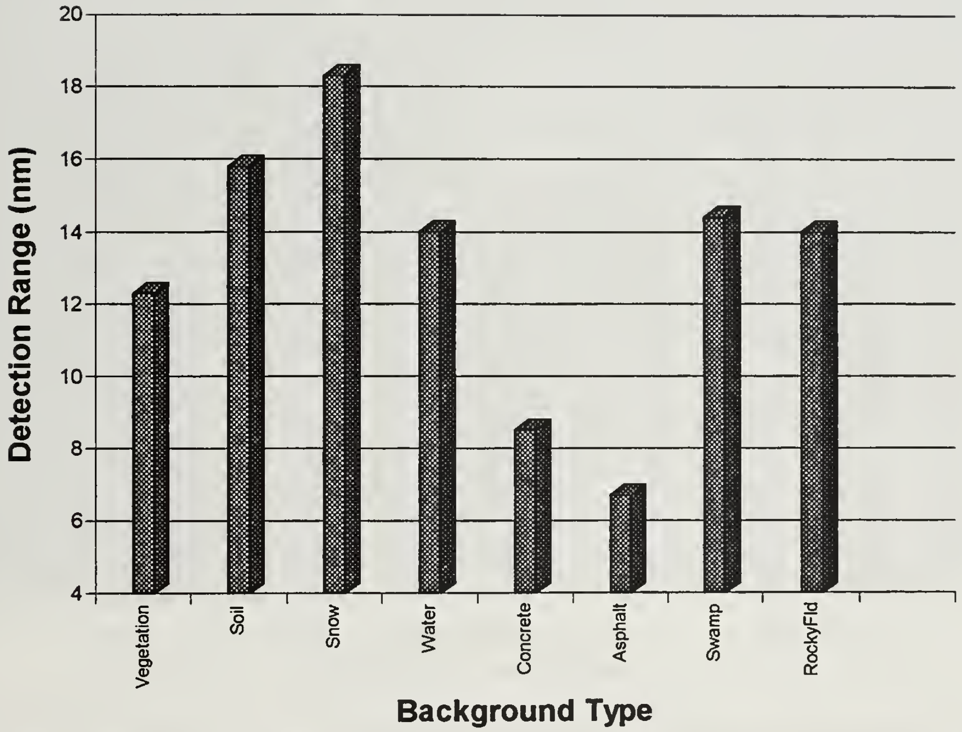


Figure 32. Detection range versus background type on 20 Jan 96/0100Z with runway target.

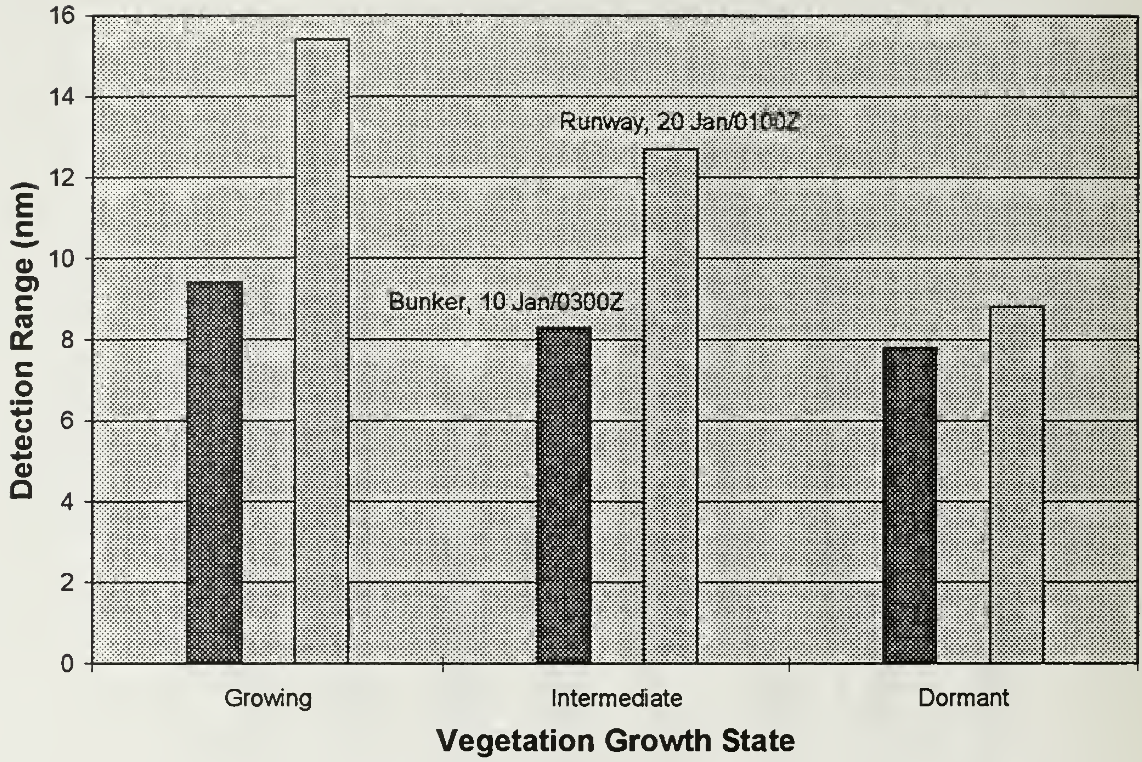


Figure 33. Detection range versus vegetation growth state on 10 and 20 Jan 96 with bunker and runway targets, respectively. In the growing state, the coverage was dense, and the moisture was wet. For the intermediate growth, coverage and moisture were both selected as intermediate. The dormant growing state had sparse coverage and dry soil moisture.

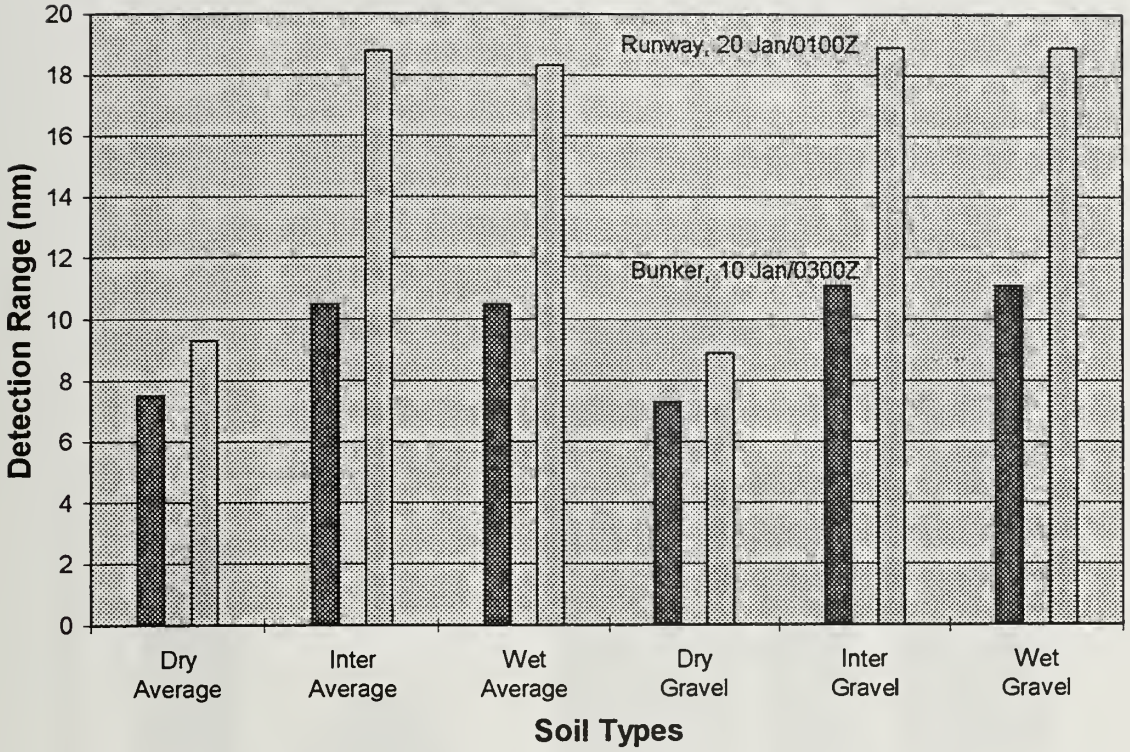


Figure 34. Effect of soil type and soil moisture on detection range on 10 and 20 Jan with bunker and runway targets, respectively.

Three specific snow conditions were tested on 10 and 20 January: fresh snow, 36 inches deep, and undisturbed; old snow, 12 inches deep, and late in season condition; and rained upon snow, 12 inches deep, and compact. For the 10 January case, the greatest detection range difference was only 1.5%. For 20 January, all detection ranges were the same.

With the water background, the user can specify water depth and water clarity. With depths of 2, 15, and 50 feet for both clear and turbid water, the greatest difference in detection ranges for both days was only 0.9%.

Of all the backgrounds in this test, concrete and the rocky field had the largest differences in detection range--71.7 and 66.9%, respectively. Samples are shown in Figures 35 and 36.

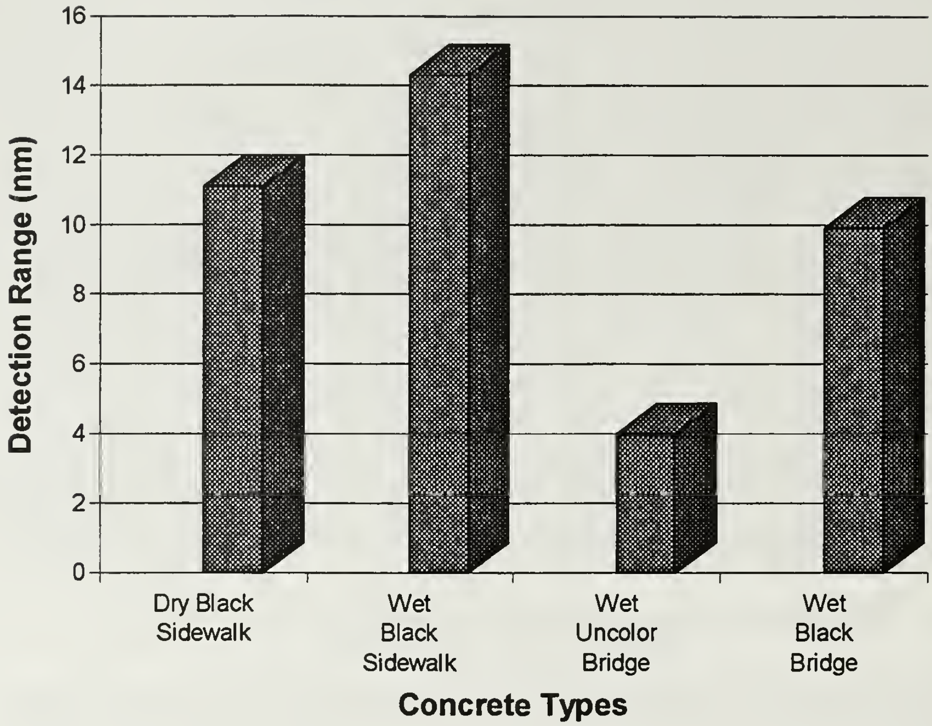


Figure 35. Detection range versus different types of concrete on 20 Jan 96/0100Z with runway target.

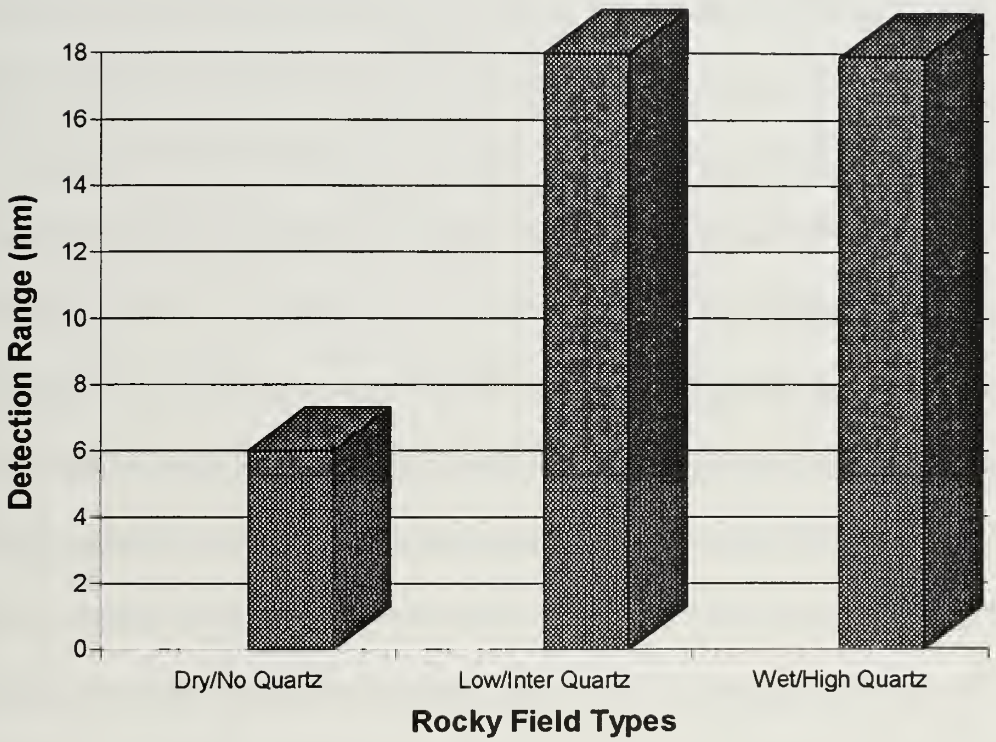


Figure 36. Quartz content and moisture of the rocky field affecting detection range on 20 Jan 96/0100Z with runway target.

III. CONCLUSIONS AND RECOMMENDATIONS

This thesis evaluated the infrared model of version 3.1 of the EOTDA to test its accuracy in target prediction based on an operational exercise in January 1996 at NAS Fallon, Nevada, and to test the sensitivity of its entry parameters. EOTDA model strengths and weaknesses were found for use by operational users and researchers.

Seven missions from the exercise were evaluated. Overall, the EOTDA performed well in that predicted target detection range errors were less than 13%, well below the 20% error standard. Given detailed target and background information and the ability to create targets from the generic target models, accurate representations of the actual targets could be created. Entering measured weather data gave an accurate representation of the atmospheric conditions, which also contributed to accurate EOTDA output. Changing weather conditions were reflected well in the EOTDA output. Significant parameters were the dewpoint temperature, type of aerosol selected, cloud cover, precipitation, and wind speed, and ground moisture.

The sensitivity study of each EOTDA parameter revealed what parameters the EOTDA is sensitive to and not sensitive to. The most sensitive parameters were dewpoint temperature, aerosol type, low cloud cover, visibility below three nautical miles, precipitation, and some of the background characteristics. Parameters that did not significantly affect EOTDA output were high clouds, scene complexity, albedo, and the water and snow background characteristics.

Additional strengths in the EOTDA are related to the NFOV MRT detection range, view directions, and some of the types of weather and visibilities. The NFOV MRT detection ranges were in good agreement with observed target detection ranges.

Deficiencies or suspect range values were found with the scud launcher target, some types of precipitation, the fog oil and desert aerosols, the boundary layer height model, some MDT values, and some of the WFOV MRT values. The scud launcher detection ranges did not vary with large changes in air temperature or dewpoint temperature. Freezing drizzle, freezing precipitation, and moderate rain showers and moderate snow showers had overpredicted detection ranges. All of the aerosols gave reasonable results, except for the fog oil and desert aerosols. Detection ranges seemed too long with the fog oil aerosol and too short for the desert aerosol. The boundary layer height model gave best correlated detection ranges when the boundary layer height is set at or above the sensor height, rather than entering the actual or a lower boundary layer height. Also, there were often no MDT solutions computed, and no correlation could be found to explain why. The WFOV MRT detection ranges were also unreliable in that occasionally there were no solutions or the values would reach an underpredicted limit.

The most important recommendation in producing accurate electro-optic forecasts is studying the target area weather in order to accurately forecast the weather conditions, and close communication with the pilots and intelligence analysts in order to know the mission and target and background compositions. When the weather forecaster understands the mission tactics, enters accurate meteorological data, and enters accurate and detailed target and background information, the EOTDA can provide an accurate prediction. Following up by attending mission debriefs, getting detailed pilot feedback, and viewing mission tapes will improve forecast accuracy and aid in development of electro-optic forecast rules of thumb. Also, it is recommended that operational electro-optic forecasters report periodically significant EOTDA findings to other users and to the research and development community. Periodic reports will help operational users learn how to use the EOTDA more effectively, and they will also help guide research and model improvements.

APPENDIX A. SAMPLE EOTDA

SECURITY CLASSIFICATION: UNCLASSIFIED

IR EXECUTION SUMMARY

20 Jan 1996 0100 Z	Sen ID:	Abs Humidity: 4.0 (g/m**3)
39° 14' N 118° 14' W	Sen Ht: 230.0 hft	4 km Trans: 0.4
		Sky Temp: 236.2 (K)
		IR Vis: 37.3 (kft)

MET INPUT

Comment RUNWAY & BUNKER
Date 19/ 1/96
Lat/Long 39°14' N/118°14' W
Temperature 32/ 47/ 29 F
Dewpoint 28 F
Aer 5 Desert

Bndy Lyr 400 hft
UL Def? Yes

NFL TAF 0909 26010KT 9999 SCT050 BKN110 QNH2984INS CIG110
BECMG 1920 32015KT 9999 BKN050 BKN110 BKN200 QNH2995INS CIG050
BECMG 2301 30020KT 9999 SCT060 SCT080 SCT110 QNH3002INS;

==

OPS/INTEL INPUT

COMMENT RUNWAY & BUNKER

TYPE IR		ELEV 4250.0 ft MSL	ALBEDO 3 DESERT
SENSOR ID	1.	TARGET 402 RW-I	1. BKGD 2 SOIL
VIEW DIR 320 deg		HEADING 30 deg	SLOPE 0 deg
SENSOR HT 230.0 hft		POSITION N/A	DIR N/A deg
COMPLEXITY NONE		OP STATE N/A	
		SPEED N/A kts	2. BKGD 8 RCKY FLD
			SLOPE 0 deg
	2.	TARGET 109 BUNKER009	DIR N/A deg
		HEADING 360 deg	
		POSITION N/A	3. BKGD 1 VEGET
		OP STATE N/A	SLOPE 0 deg
		SPEED N/A kts	DIR N/A deg

Soil Parameters	Type	Surface Moisture	Depth Moisture
	Average	Dry	Intermediate
Rocky Field Parameters	Quartz Concent.	Surface Moisture	Depth Moisture
	Low	Dry	Intermediate
Veget Parameters	Growing State	Coverage	Soil Moisture
	Dormant	Sparse	Dry

TARGET 1: RW-I | TGT HEADING: 30 deg

BACKGROUND 1: SOIL | View Dir: 320 deg

Soil Parameters	Type	Surface Moisture	Depth Moisture
	Average	Dry	Intermediate

VIEW DIR	MRT Det Rng (kft)		MDT Det Rng (kft)	
(deg)	NFOV	WFOV	NFOV	WFOV
0	44.2	41.8	-1.0	-1.0
45	34.4	31.9	-1.0	-1.0
90	52.2	49.1	-1.0	-1.0
135	53.5	50.4	-1.0	-1.0
180	44.2	41.8	-1.0	-1.0
225	34.4	31.9	-1.0	-1.0
270	52.2	49.1	-1.0	-1.0
315	53.5	50.4	-1.0	-1.0
320	53.5	49.8	-1.0	-1.0

VIEW DIR	MRT Delta-T (K)		MDT Delta-T (K)	
(deg)	NFOV	WFOV	NFOV	WFOV
0	-1.9	-1.9	0.0	0.0
45	-1.9	-1.9	0.0	0.0
90	-1.9	-1.9	0.0	0.0
135	-1.9	-1.9	0.0	0.0
180	-1.9	-1.9	0.0	0.0
225	-1.9	-1.9	0.0	0.0
270	-1.9	-1.9	0.0	0.0
315	-1.9	-1.9	0.0	0.0
320	-1.9	-1.9	0.0	0.0

VIEW DIR	BKGND Temp	MRT TGT Temp (K)		MDT TGT Temp (K)	
(deg)	(K)	NFOV	WFOV	NFOV	WFOV
0	275.9	274.0	274.0	0.0	0.0
45	275.9	274.0	274.0	0.0	0.0
90	275.9	274.0	274.0	0.0	0.0
135	275.9	274.0	274.0	0.0	0.0
180	275.9	274.0	274.0	0.0	0.0
225	275.9	274.0	274.0	0.0	0.0
270	275.9	274.0	274.0	0.0	0.0
315	275.9	274.0	274.0	0.0	0.0
320	275.9	274.0	274.0	0.0	0.0

==

BACKGROUND 2: RCKY FLD — View Dir: 320 deg

Rocky Field Parameters Quartz Concent.	Surface Moisture	Depth Moisture
Low	Dry	Intermediate

VIEW DIR	MRT Det Rng	(kft)	MDT Det Rng	(kft)
(deg)	NFOV	WFOV	NFOV	WFOV
0	44.8	43.0	-1.0	-1.0
45	35.6	33.2	-1.0	-1.0
90	53.5	50.4	-1.0	-1.0
135	54.7	51.6	-1.0	-1.0
180	44.8	43.0	-1.0	-1.0
225	35.6	33.2	-1.0	-1.0
270	53.5	50.4	-1.0	-1.0
315	54.7	51.6	-1.0	-1.0
320	54.1	51.0	-1.0	-1.0

VIEW DIR	MRT Delta-T	(K)	MDT Delta-T	(K)
(deg)	NFOV	WFOV	NFOV	WFOV
0	-2.0	-2.0	0.0	0.0
45	-2.0	-2.0	0.0	0.0
90	-2.0	-2.0	0.0	0.0
135	-2.0	-2.0	0.0	0.0
180	-2.0	-2.0	0.0	0.0
225	-2.0	-2.0	0.0	0.0
270	-2.0	-2.0	0.0	0.0
315	-2.0	-2.0	0.0	0.0
320	-2.0	-2.0	0.0	0.0

VIEW DIR	BKGND Temp	MRT TGT Temp (K)		MDT TGT Temp (K)	
(deg)	(K)	NFOV	WFOV	NFOV	WFOV
0	276.0	274.0	274.0	0.0	0.0
45	276.0	274.0	274.0	0.0	0.0
90	276.0	274.0	274.0	0.0	0.0
135	276.0	274.0	274.0	0.0	0.0
180	276.0	274.0	274.0	0.0	0.0
225	276.0	274.0	274.0	0.0	0.0
270	276.0	274.0	274.0	0.0	0.0
315	276.0	274.0	274.0	0.0	0.0
320	276.0	274.0	274.0	0.0	0.0

==

BACKGROUND 3: VEGET View Dir: 320 deg

Veget Parameters	Growing State	Coverage	Soil Moisture
	Dormant	Sparse	Dry

VIEW DIR (deg)	MRT Det Rng (kft) NFOV	MRT Det Rng (kft) WFOV	MDT Det Rng (kft) NFOV	MDT Det Rng (kft) WFOV
0	49.8	47.3	46.1	46.1
45	40.5	38.7	46.1	46.1
90	57.8	54.7	46.1	46.1
135	59.6	55.9	46.1	46.1
180	49.8	47.3	46.1	46.1
225	40.5	38.7	46.1	46.1
270	57.8	54.7	46.1	46.1
315	59.6	55.9	46.1	46.1
320	59.0	55.3	46.1	46.1

VIEW DIR (deg)	MRT Delta-T (K) NFOV	MRT Delta-T (K) WFOV	MDT Delta-T (K) NFOV	MDT Delta-T (K) WFOV
0	-2.6	-2.6	-2.6	-2.6
45	-2.6	-2.6	-2.6	-2.6
90	-2.6	-2.6	-2.6	-2.6
135	-2.6	-2.6	-2.6	-2.6
180	-2.6	-2.6	-2.6	-2.6
225	-2.6	-2.6	-2.6	-2.6
270	-2.6	-2.6	-2.6	-2.6
315	-2.6	-2.6	-2.6	-2.6
320	-2.6	-2.6	-2.6	-2.6

VIEW DIR (deg)	BKGND Temp (K)	MRT TGT Temp (K) NFOV	MRT TGT Temp (K) WFOV	MDT TGT Temp (K) NFOV	MDT TGT Temp (K) WFOV
0	276.6	274.0	274.0	274.0	274.0
45	276.6	274.0	274.0	274.0	274.0
90	276.6	274.0	274.0	274.0	274.0
135	276.6	274.0	274.0	274.0	274.0
180	276.6	274.0	274.0	274.0	274.0
225	276.6	274.0	274.0	274.0	274.0
315	276.6	274.0	274.0	274.0	274.0
320	276.6	274.0	274.0	274.0	274.0

==

TARGET 2: BUNKER009 TGT HEADING: 360 deg

	BACKGROUND 1: SOIL		View Dir: 320 deg
Soil Parameters	Type	Surface Moisture	Depth Moisture
	Average	Dry	Intermediate

VIEW DIR	MRT Det Rng	(kft)	MDT Det Rng	(kft)
(deg)	NFOV	WFOV	NFOV	WFOV
0	31.9	-1.0	-1.0	23.9
45	37.5	-1.0	-1.0	25.8
90	32.5	-1.0	183#	30.1
135	35.0	-1.0	28.2	28.2
180	28.8	-1.0	23.9	23.9
225	34.4	-1.0	3#	27.6
270	31.9	-1.0	186#	29.5
315	36.8	-1.0	-1.0	91#
320	36.8	-1.0	-1.0	90#

VIEW DIR	MRT Delta-T	(K)	MDT Delta-T	(K)
(deg)	NFOV	WFOV	NFOV	WFOV
0	2.8	0.0	0.0	2.8
45	2.8	0.0	0.0	2.8
90	2.6	0.0	0.0	2.8
135	2.4	0.0	2.8	2.8
180	2.3	0.0	2.8	2.8
225	2.3	0.0	0.0	2.7
270	2.5	0.0	0.0	2.7
315	2.7	0.0	0.0	0.0
320	2.8	0.0	0.0	0.0

VIEW DIR	BKGND Temp	MRT TGT Temp (K)		MDT TGT Temp (K)	
(deg)	(K)	NFOV	WFOV	NFOV	WFOV
0	275.9	278.7	0.0	0.0	278.7
45	275.9	278.7	0.0	0.0	278.7
90	275.9	278.5	0.0	0.0	278.7
135	275.9	278.2	0.0	278.7	278.7
180	275.9	278.1	0.0	278.7	278.7
225	275.9	278.2	0.0	0.0	278.5
270	275.9	278.3	0.0	0.0	278.5
315	275.9	278.6	0.0	0.0	0.0
320	275.9	278.6	0.0	0.0	0.0

BACKGROUND 2: ROCKY FIELD View Dir: 320 deg

Rocky Field Parameters	Quartz Concent.	Surface Moisture	Depth Moisture
	Low	Dry	Intermediate

VIEW DIR	MRT Det Rng	(kft)	MDT Det Rng	(kft)
(deg)	NFOV	WFOV	NFOV	WFOV
0	31.3	-1.0	-1.0	23.9
45	36.8	-1.0	-1.0	25.8
90	31.9	-1.0	185#	29.5
135	33.8	-1.0	27.6	27.6
180	27.6	-1.0	23.9	23.9
225	33.2	-1.0	8#	27.0
270	30.7	-1.0	189#	29.5
315	36.2	-1.0	-1.0	96#
320	36.2	-1.0	-1.0	95#

VIEW DIR	MRT Delta-T	(K)	MDT Delta-T	(K)
(deg)	NFOV	WFOV	NFOV	WFOV
0	2.7	0.0	0.0	2.7
45	2.7	0.0	0.0	2.7
90	2.5	0.0	0.0	2.7
135	2.3	0.0	2.7	2.7
180	2.1	0.0	2.7	2.7
225	2.2	0.0	0.0	2.5
270	2.3	0.0	0.0	2.5
315	2.6	0.0	0.0	0.0
320	2.6	0.0	0.0	0.0

VIEW DIR	BKGND Temp	MRT TGT Temp (K)		MDT TGT Temp (K)	
(deg)	(K)	NFOV	WFOV	NFOV	WFOV
0	276.0	278.7	0.0	0.0	278.7
45	276.0	278.7	0.0	0.0	278.7
90	276.0	278.5	0.0	0.0	278.7
135	276.0	278.2	0.0	278.7	278.7
180	276.0	278.1	0.0	278.7	278.7
225	276.0	278.2	0.0	0.0	278.5
270	276.0	278.3	0.0	0.0	278.5
315	276.0	278.6	0.0	0.0	0.0
320	276.0	278.6	0.0	0.0	0.0

BACKGROUND 3: VEGET View Dir: 320 deg

Veget Parameters	Growing State	Coverage	Soil Moisture
	Dormant	Sparse	Dry

VIEW DIR	MRT Det Rng	(kft)	MDT Det Rng	(kft)
(deg)	NFOV	WFOV	NFOV	WFOV
0	26.4	-1.0	-1.0	119#
45	32.5	-1.0	-1.0	25.8
90	27.0	-1.0	199#	27.0
135	28.8	-1.0	25.2	25.2
180	23.9	-1.0	118#	118#
225	28.2	-1.0	-1.0	-1.0
270	25.8	-1.0	-1.0	-1.0
315	31.9	-1.0	-1.0	128#
320	31.9	-1.0	-1.0	126#

VIEW DIR	MRT Delta-T	(K)	MDT Delta-T	(K)
(deg)	NFOV	WFOV	NFOV	WFOV
0	1.9	0.0	0.0	0.0
45	2.0	0.0	0.0	2.1
90	1.8	0.0	0.0	2.1
135	1.6	0.0	2.1	2.1
180	1.6	0.0	0.0	0.0
225	1.5	0.0	0.0	0.0
270	1.7	0.0	0.0	0.0
315	1.9	0.0	0.0	0.0
320	2.0	0.0	0.0	0.0

VIEW DIR	BKGND Temp	MRT TGT Temp (K)		MDT TGT Temp (K)	
(deg)	(K)	NFOV	WFOV	NFOV	WFOV
0	276.6	278.5	0.0	0.0	0.0
45	276.6	278.6	0.0	0.0	278.7
90	276.6	278.4	0.0	0.0	278.7
135	276.6	278.2	0.0	278.7	278.7
180	276.6	278.2	0.0	0.0	0.0
225	276.6	278.1	0.0	0.0	0.0
270	276.6	278.3	0.0	0.0	0.0
315	276.6	278.6	0.0	0.0	0.0
320	276.6	278.6	0.0	0.0	0.0

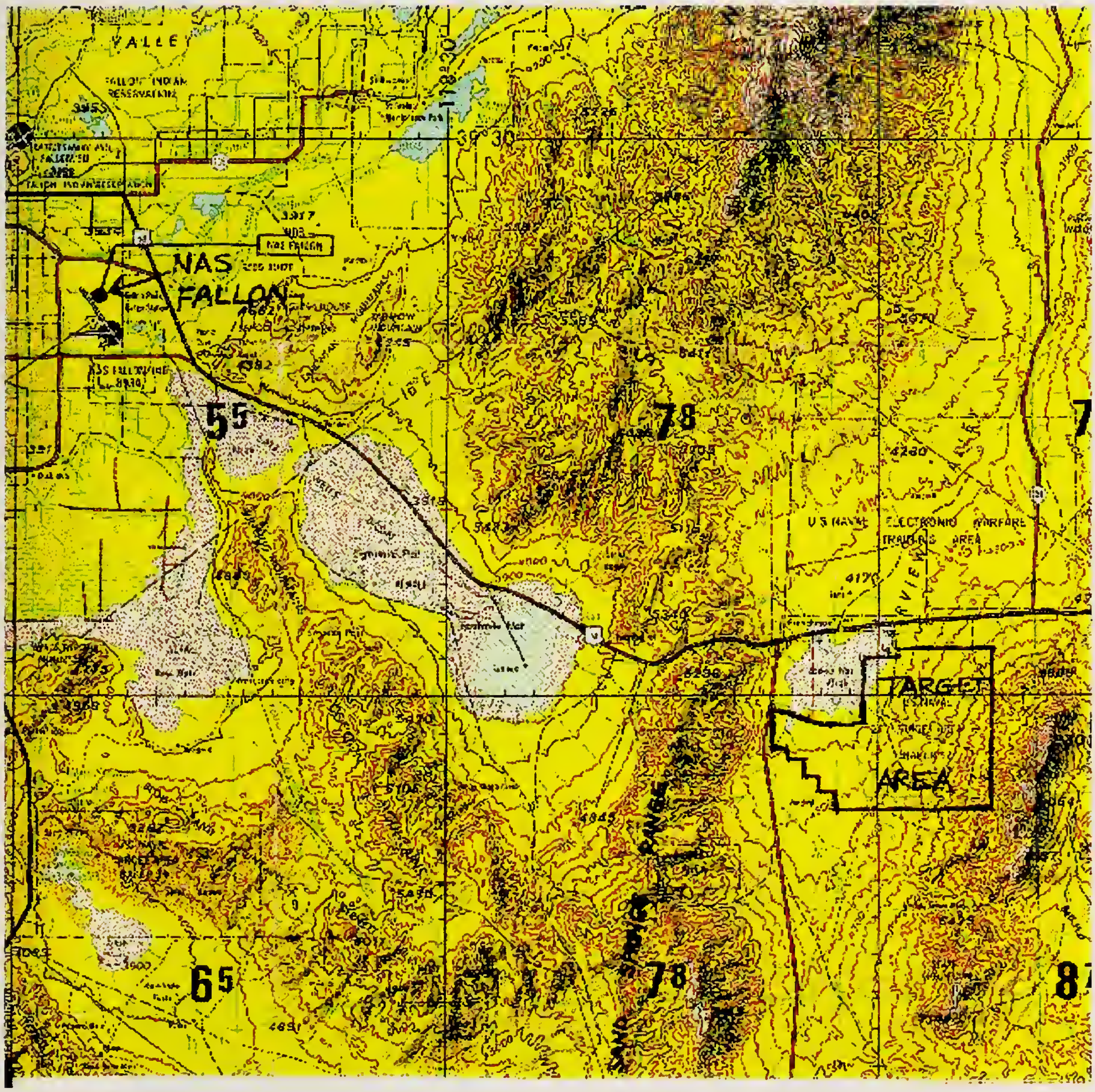
0.0 -> No value computed.
-1.0 -> No solution possible.
-2.0 -> Sensor is above overcast.
-> Reduce sensor height (xxx hft).

HOT-TO-COLD LIST

VEGET (3) RCKY FLD (2) SOIL (1) RW-I

NOTE: Temperatures are based on MRT WFOV

APPENDIX B. MAP OF FALLON EXERCISE AREA



APPENDIX C. TARGET PHOTOGRAPHS

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